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Vol. XI. No. 2. NOVEMBER, 1948

THE ENGLISH ELECTRIC JOURNAL

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Published by

THE ENGLISH ELECTRIC COMPANY LIMITED

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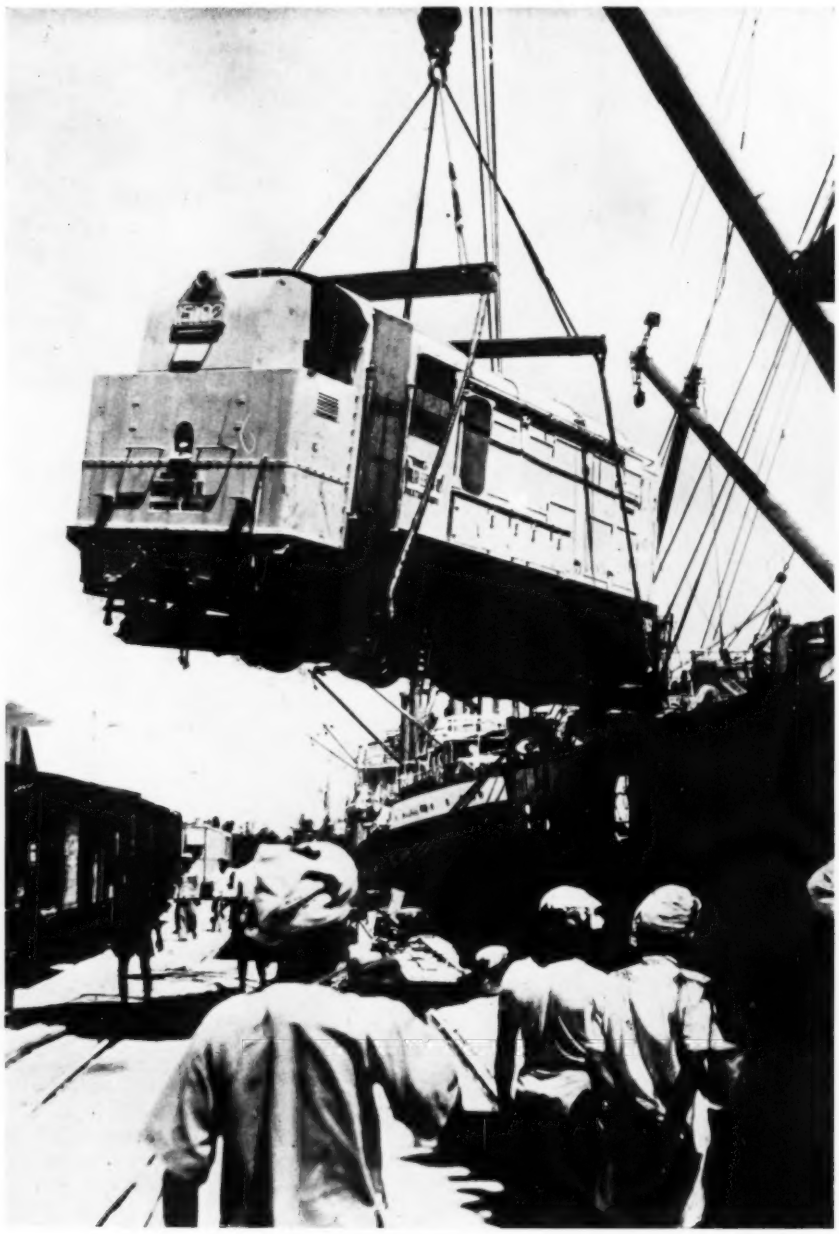


Unloading at Port Swettenham, Malaya, the first of twenty 350 h.p. diesel-electric shunting locomotives which are being supplied to the Malayan State Railways.

The
English Electric
Journal

Vol. XI. No. 2 NOVEMBER, 1948. One Shilling

The Automatic Control of Hydro-Electric Power Stations.

By E. G. TEASDALE, B.A., Hydraulic Section, Stafford.

General Considerations.

There are a number of reasons why the automatic control of hydro-electric generating units should be desirable, and why a considerable number of fully automatic installations have already been made, whereas automatic steam-driven units, if any such exist, are extremely rare.

The main reason is one of topography. A water power station cannot be built where it is most needed, or where it will be most convenient; it has to be built where the power is available in sufficient quantity to justify the development. The fact that there must be a difference in level available to give the turbine its "head," combined with a constant supply of water at the higher level, usually restricts the choice of suitable sites very severely.

A steam station is invariably situated reasonably close to the load centre that it is to serve. Often, if the fuel be coal, this requirement also ensures that the station is reasonably close to supplies of fuel. In any case, the fuel can be brought to the station in any desired quantity, and the size of the station, that is to say the installed capacity of the generating plant, is not subject to other restriction than the demand for its power output. The modern tendency is thus quite naturally towards large power stations, and certainly away from a number of small power stations comparatively close together and serving one area.

The "fuel" cannot, however, be brought to the water power station; the station must go to the water power site, and, what is more, the amount of power is, in nearly all cases, strictly limited. The head obviously cannot exceed some maximum figure for any given site, and when the dams, storage reservoirs, diversion channels, and suchlike have been built, the total quantity of water that can be made available over some long period, say ten years, is also known, and cannot be increased. There is a fair amount of latitude in the choice of the total capacity of plant to be installed, but it is obvious that there is a simple inverse relation between the installed capacity and the average load factor at which the station will have to operate.

The inherent nature of water power thus operates in the opposite direction to the modern tendency for a few large power stations, and in general a system that depends mainly on water power is fed by a number of power stations, of varying sizes, and situated quite arbitrarily so far as concerns their positions relative to each other and to the centres of load. They may be separated by great distances, and one or more may be in remote places difficult of access. On the other hand, in the sort of country that lends itself to the development of water power, it often happens that there are a number of suitable locations quite close together, but far enough apart to prevent the combination of the available heads into a single fall, and to make it uneconomic to develop the power otherwise than in a number of separate stations. Examples of such systems of associated power stations are the completed Galloway development in South Western Scotland and the Kiewa River scheme in the State of Victoria, in which the first of four or five power stations is in operation and the second is at present under construction.

If each of these separate power stations had to have a complete operating staff to keep it

running for twenty-four hours a day, the running and maintenance charges (for staff) of the whole system would compare very unfavourably with those of a single steam power station having the same total output. It is evident that great savings can be obtained by arranging for certain chosen stations to run automatically, or by remote control from one of the others, without permanent operating staff. In some cases the degree of automatic control is not so great, and the sets are arranged for manual starting by semi-skilled staff, but are provided with fully automatic protection so that they shut down safely of themselves in any conceivable set of abnormal circumstances. Many variations are possible, giving all degrees of control, between the manually controlled set with rather more than the minimum amount of automatic protection, and the completely automatic set that will start up from rest, deliver load to the system, and shut down again without any human intervention.

Methods of Control.

The engineer who has to consider how to achieve automatic working gets away to a flying start when dealing with water turbines. The turbine is provided with an automatic governor irrespective of the type of control to be adopted in the power station, and the water turbine governor is a highly developed piece of machinery, almost uncanny in its precision of operation. The main principle upon which it works is that of the hydraulic servo-motor. Fluid under pressure is admitted to one side or the other of a piston, free to move in a cylinder.

This principle, used in several different variations in the governor and the actuator (which is the " brain " of the governor system), is applicable to other parts of the control of a turbine and of its accessories. The fluid may be oil, or it may be water. Water under pressure necessarily exists wherever a water turbine is to run ; a supply of oil under pressure is maintained by an auxiliary pump. In general it may be said that, if there is a way of carrying out any desired operation in connection with turbine control by hydraulic means, such control is more sure and more simple that if the operation were carried out by electric means.

Nethertheless, electricity plays by far the more important part in the control scheme for the set as a whole. The simple and reliable automatic control scheme is the one in which the two fundamental principles—that of the hydraulic relay (or servo-motor) and that of the electric relay (or solenoid or contactor)—have been intelligently wedded together.

For the starting operations to be carried out without local human aid, supplies of energy must be available in some form or other. In many cases the transmission system to which the station is connected is always " alive " from some other source, and low-voltage A.C. is normally available from a step-down auxiliary transformer. It is well, however, to cater for the abnormal, and an automatic station should to be capable of starting up when the bus-bars are " dead." It is essential that electric energy is available from a charged storage battery, and all the most vital circuits are fed from this source. Hydraulic energy is usually available from a pressure receiver in which a quantity of oil is stored, and in which the pressure is maintained by a cushion of compressed air.

General Sequence of Operations.

For the purpose of this article the power station will be taken to include the pipeline and the intake to it, but not any further intake works upstream, such as tunnel or open channel. There will always be at least one means of cutting off the water from the turbine. This may be a sluice gate or valve at the upstream end of the pipeline, or it may be an inlet valve between the pipeline and the turbine. In many cases, of course, there will be such means of interrupting the flow of water at both ends of the pipeline. For an automatic station it is essential that the apparatus normally used for stopping the water be automatically operated ; if it is a sluice gate it will be raised and lowered by electric motor ; if it is a valve it may be either motor-operated or hydraulically operated, but in the latter case it must have a link, in the form of a solenoid, with the electric control system.

The impulse for an automatic start may come from one of many sources. If the running of the station is to be dependent on the water available, the impulse may be given by a float switch. If the station is to run according to the load demand on the system, the impulse may come from a wattmeter in another station. In the majority of cases it will be given, via push-button or otherwise, by the controller at some central control point.

The starting impulse will energise a master relay or contactor, which will remain energised during the whole period that the set is running. In series with its coil will be numerous protective devices to ensure that the master relay cannot close unless everything is in safe running order. The operation of the master relay is followed by the starting of the auxiliaries, and, in due course, by the starting of the main set.

A hydro-electric set has few auxiliaries : the governor oil-pump, usually driven by an A.C. motor ; the turbine lubricating oil pump, which may be gear driven from the main shaft or motor

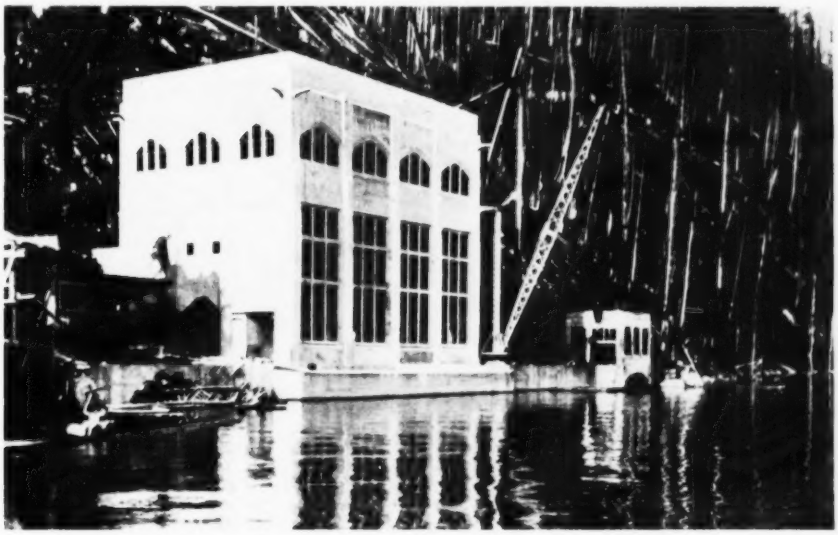


Fig. 1.—Alouette hydro-electric station, British Columbia, which operates automatically under remote control from another station 10½ miles distant.

driven, but which in any case will be accompanied by a stand-by oil pump, driven by D.C. motor, and used for ensuring an oil supply while the turbine is starting up or shutting down ; alternator lubricating oil pumps, usually two and either both driven by an A.C. motor or one by A.C. and one by a D.C. motor ; and an air-compressor set, which supplies high-pressure air to the governor oil system and low-pressure air to the alternator brakes.

The air-compressor set is frequently an independent unit, fully automatic but completely outside the automatic sequence of the main sets. This is all the more desirable, as there is usually only one compressor equipment for the power station, irrespective of the number of main generating sets. It is advisable for this equipment to have two motor-driven compressors, one stand-by to the other. The compressor motor is under the control of an air-pressure relay connected to the main pressure receiver, and runs as necessary (providing that the low-voltage A.C. supply is available) to maintain the pressure in the receiver within two predetermined limits.

Other small motors connected with the turbine have not been mentioned, because they are not auxiliaries in the same sense of the word as those already considered. They are : the governor pendulum motor, which forms a detached electrical system with the governor alternator mounted on the main shaft ; the governor speeder-motor, which is a fractional h.p. motor for altering the governor setting ; and possibly a dewatering pump and motor, which is in a different category altogether, as it does not have to operate when the main set is running, but is chiefly used when there is maintenance to be done. For this reason the dewatering pump does not have to be considered in connection with automatic operation.

In the starting, running up to speed, synchronising, and loading of a hydro-electric set there are naturally a number of operations that have to be performed in a particular order. The principle adopted for automatic control is that the operating circuit for each stage of the sequence is completed in turn by electrical contacts that are closed only when the preceding operation has either been completed or has progressed sufficiently far. The devices that are used for this checking or sequencing are simple enough in themselves : pressure relays are used to detect when air, oil, or water pressure in certain piping or vessels has reached a certain value ; flow relays detect oil or water flow in pipes in the same way ; and mechanical movement is certified as having taken place by limit switches or auxiliary switches operated by the moving part.

The " active " member of an electric circuit, i.e., the device that is energised, may be a relay or contactor, acting as the intermediary for another electric circuit, or it may be a solenoid or motor to cause actual mechanical movement of some part of the equipment.

Returning to the starting impulse and the closing of the master relay, the steps in the starting sequence of the main unit are :

1. The turbine casing (in the case of a reaction turbine), or the inlet pipe and bends up to the spears (in the case of an impulse turbine) have to be filled with water under pressure. For this, the main valve (or sluice gate) is " crack-opened," or alternatively a small by-pass valve is opened.
2. The main valve (or sluice gate) has to be fully opened.
3. The guide vanes (of a reaction turbine) or the spear (of an impulse turbine) has to be opened to admit water, so that the turbine runs up to speed.
4. The governor has to take control and to adjust the speed to agree closely with synchronous speed.
5. The alternator field switch (if open) has to be closed, and the automatic voltage regulator has to adjust the voltage to agree closely with the system voltage.
6. The speed matcher, operating on the governor, has to adjust the speed exactly to synchronous speed, and the automatic synchroniser has to check frequency, relative phasing, and voltage, and to give the impulse for—
7. The automatic closing of the main circuit-breaker.
8. The governor setting has to be altered so that the machine takes the desired amount of load.

Protection.

At all stages of the foregoing sequence of starting operations, as well as during all subsequent running, the set must be fully protected against the effects of any fault that may develop. One special form of protection may be mentioned first, as it only operates during the starting period. When the master relay closes it energises (among other things) a total-time relay, which has an adjustable time delay somewhat longer than the normal time required for the starting to be completed. Should this relay close its contacts it causes the stopping sequence to commence, irrespective of the stage that has been reached in the starting sequence. The circuit of the total-time relay is of course broken when the last stage of the starting sequence has been successfully completed.

Due to this necessity of being able to begin a shutting down sequence at any moment after the beginning of a starting sequence, it is usual for the master relay to energise a stopping relay (so called, but a much better name would be " setting relay "), and so at the very outset to prepare circuits for the ultimate shut down. The stopping relay has to remain closed throughout the whole running period, and as it is advisable to keep the constant load on the station battery to the minimum, the stopping relay may be of the latch-in type, cutting off its own coil.

In the case of the fully automatic unattended station, all faults have to cause shut down. Where there are attendants in the station, certain minor faults may be arranged to give a warning only. Shutting down takes place through the intermediate operation of relays of the lock-out type, so that once one of them has operated, a visit to the station to ascertain and rectify the cause of the shut down is necessary. It is usual for there to be at least two lock-out relays, and for the various faults to be grouped into those serious enough to warrant immediate shut down of the unit regardless of the shock to the supply system, and those not so serious, which allow the shut down to take place gradually and in an orderly manner. The first of the two lock-out relays will cause field switch, main circuit breaker, turbine governor, and main valve all to be " tripped " immediately, but the second lock-out relay will commence a sequenced shut down by acting only on the turbine governor to begin with. The turbine closes and rejects load, and the main circuit-breaker opens only when the load has come to zero.

For the guidance of maintenance engineers, it is usual for each separate fault to operate an annunciator flag, which, of course, has to be reset by hand. The usual faults against which protection is given are :

Overspeed.
Overvoltage.
Differential protection.
Overload.
Field failure.
Failure of pendulum drive.
Overheated windings.
Hot bearings.
Loss of lubricating oil.
Loss of governor oil pressure.
Overheated cooling air.

The division of these into the two groups is to some extent a matter of opinion, and has not been attempted here, but in general the more serious faults are given first.

Shutting Down.

In a general way, shutting down involves the reversing of the starting sequence, as regards both the individual operations and the order in which they take place. There are, however, one or two problems inherent in the shutting down which introduce factors that do not have to be considered during the starting sequence.

There are circumstances in which the turbine governor will detect faulty conditions and will shut the turbine down from working as a turbine,

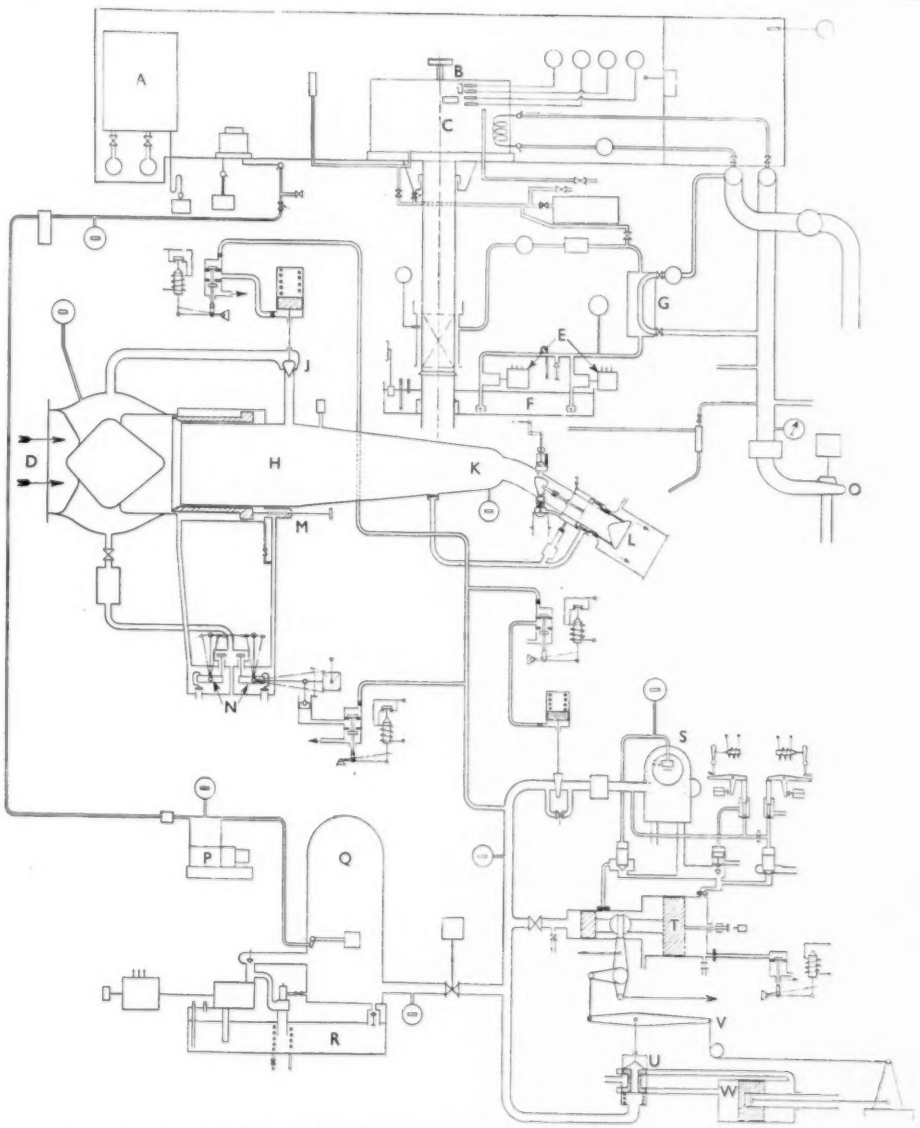


Fig. 2.—Diagram of Automatic Regulation for 36,000 b.h.p. Reaction Type Hydro-Electric Plant.

A Generator coolers.
B Overspeed device.
C Alternator.
D Entry from penstock.
E Automatic lubricating pump sets.
F Lubricating oil sump.
G Oil cooler.
H Automatic, cylindrical, and balanced inlet valve.
J Bypass.
K Turbine spiral casing.
L Automatic, cylindrical, and balanced relief valve.
M Asymptotic operating device.
N Automatic control valves.
O Cooling pump.
P Air compressor set.
Q Automatic oil pumping plant and pressure receiver.
R Oil sump.
S Automatic governor actuator.
T Pilot servo-motor.
U Main distributing valve.
V Return motion gear.
W Servo-motor operating swivel gate.

(Previously printed in the Proceedings of the Institution of Mechanical Engineers, 1947, recording Centenary Lecture by P. W. Seewer, D.E. M.I.Mech.E.)

but, unless special provision is made, the healthy electrical end will continue in operation, the alternator running as a synchronous motor and maintaining the speed of the set. The simplest way to prevent such reverse operation is to use a turbine govenor limit switch and a time delay relay, arranged to lock out the master relay if the turbine gates stay shut for more than a few seconds. The delay is necessary because the gates may close for a very short time during normal operation when load is thrown off.

What is perhaps the most complicated part of the shutting down circuits is that which deals with the brakes. Brakes are always fitted to a vertical shaft set, because it is during very slow running that the thrust bearing is most likely to suffer damage. They are sometimes fitted to a horizontal shaft set, for a similar reason. The moment of inertia of a water-wheel alternator rotor is usually large, and if left to itself the rotor will continue rotating at a low speed for a very long time. The high value of stored energy also means that work has to be done at a high rate when the rotor is brought to rest quickly by the brakes. The brakes are designed so that no harm results if they are applied at full normal operating speed, but there is no need to put them on at so high a speed, because unaided deceleration is great enough to begin with; it is the long drawn out running at low speed that is to be avoided.

Under certain faulty conditions a water turbine can run at a very high overspeed, rarely less than 1.8 times normal, and often considerably more than this. Although overspeeding is a very rare occurrence, it is necessary to ensure that the brakes do not go on when the speed is above normal, and this has usually been done by means of a time delay. The worst case that can happen is shutting down from maximum overspeed, and the time delay is set to ensure that the brakes do not, in this case, go on until the speed has dropped at least to normal. Because the time delay remains the same whatever the speed at the beginning of shut down, and because nearly every shut down takes place from normal speed, the speed when the brakes go on is usually about half normal.

A second time delay is used to take the brakes off again. This must be long enough to allow the set to come to rest under the influence of the brakes, even when shutting down from maximum overspeed. A third time delay has been used in connection with the brake circuits. When the main set has come to rest there are still operations in the stopping sequence to be carried out. The shutting down of the auxiliaries, for instance, takes place after the brakes have come off. A fault in the compressed air system is not impossible, and it might be that the brakes have failed to go on. To look after this possibility, and to ensure the completion of the stopping sequence, the third time delay, with a very long setting, causes the auxiliaries to shut down after an interval during which the main rotor must have come to rest even without the aid of the brakes.

The last operation in automatic shut down is the energising of a re-setting relay, to drop out the latched-in stopping relay. As the latter cuts off the coil of the re-setting relay, the whole apparatus is left dead," that is to say disconnected from the battery, and, provided that the shut down has not taken place by the operation of a lock-out relay, the equipment is ready for a fresh automatic start when the next starting impulse is given.

Remote Control.

By far the greater number of automatic stations are under human control from a remote point. The units are truly automatic in the sense that they go through all the processes of starting up and of shutting down, as described above, without the need for any attendants on the spot, but it is usual for human intervention to decide when the sets are to run, and how much load they are to give. The method of remote control adopted depends to a great extent on the degree of control required, and to some extent on the distance between the station and the control point.

When that distance exceeds a few hundred yards, the cost of the pilot wires becomes of importance. Straightforward remote control needs, in general, one pilot wire per operation to be carried out, plus a common return. If the remote control is to be limited to pressing one push button to start a set up and pressing another to shut it down again, and if there are only one or two sets in the automatic station, then the small number of pilot wires required and the simplicity of the apparatus renders it uneconomical to consider any but the most direct form of remote control.

On the other hand, it is sometimes desired that the operator at the control point should be able to exercise almost as much control over the running of the set as though he were in a control room at the power station itself and had the services of a turbine driver in the machine room. For this a special type of apparatus, giving " supervisory control," has been developed, based on the type of relay and of circuits associated with automatic telephone exchanges. The number of pilot wires required is very small, and with four—i.e., two pairs—all the facilities usually required can be given.

It is possible to divide the starting sequence into all its separate stages, putting each one under the control of the distant operator. Each stage, as it is completed, sends a signal to that effect and causes a lamp to light on the control board, and the operator has to despatch a fresh impulse to cause the next stage to be carried out. In practice, it is usual for the automatic running up to proceed from the first starting impulse to the point when the set is ready for synchronising. The usual readings of voltage and frequency must be transmitted from the station to the control board, and the operator, during the time that he has these readings in front of him, must have full control of both speed and voltage, and be able to close the distant circuit-breaker.

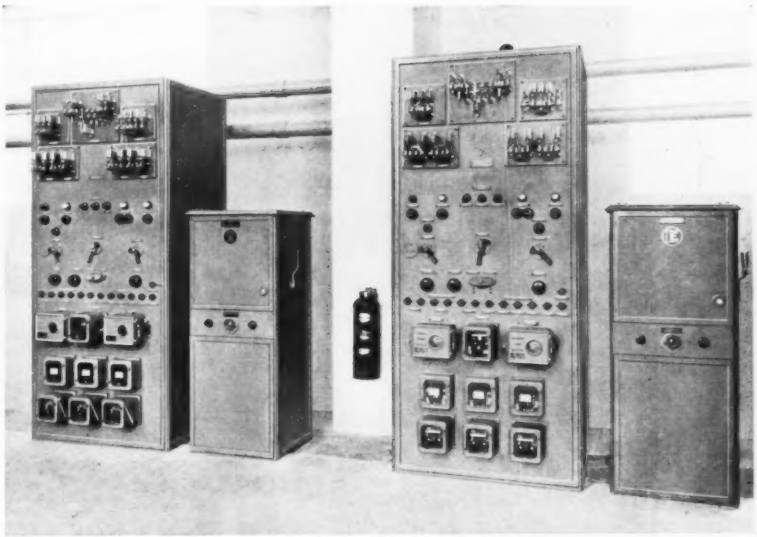


Fig. 3.—Automatic control panels and alternator field suppression switch cubicles at the Earlstoun power station of the Galloway Water Power Scheme, Scotland.

During subsequent running, too, it is necessary for a number of signals to be transmitted simultaneously both ways. Readings of voltage, current, and watts are desirable, and the operator must of course be able to control the turbine governor setting and the voltage regulator setting. In addition, the apparatus must signal the occurrence of any change of state in the power station equipment that should be known to the operator to enable him to carry out his supervisory duties properly.

Apparatus.

The electrical relays that are built into the automatic equipment proper are products of heavy engineering. Although in general they have to deal with only small currents, their contacts and other parts are made extremely robust. Provided that the recommended amount of maintenance is carried out, a complicated set of automatic equipment will operate for years without giving trouble, after being properly adjusted and put into service.

The supervisory control gear, by way of contrast, is decidedly the product of light telephone engineering. A light relay, occupying no more than a few cubic inches, may have several score of contacts, which deal of course with minute currents at very low voltage. Whole banks of these relays are mounted close together, so that a comparatively small cubicle is all that is required at the power station to house all the apparatus dealing with incoming and outgoing signals. There will be a similar cubicle at the remote point. The control board is generally of the miniature type, with mimic diagram, pea-type indicating lamps, and compact arrangement of control switches and push buttons.

Some Special Plants.

More then twenty years ago The English Electric Company supplied a 10,000 kVA completely automatic set to the British Columbia Electric Railway Company for their Alouette Power Station. This station, shown in Fig. 1, is in a very inaccessible location 10½ miles from the manually controlled station at Stave Lake. The remote control is of a form as simple as it is possible to make it. The closing of the breaker at the Stave Lake end of the transmission line from Alouette causes the set to start up, synchronise, and supply power to the system at a predetermined value. The opening of the same breaker causes the set to shut down.

The only power yet developed at the Victoria Falls of the Zambesi is that given by two 1,000 kW automatically controlled units. At present, the units run one at a time, and there is no need for automatic synchronising. When the load justifies the addition of more units, automatic synchronising can easily be added. There is no remote control, and the starting impulse is

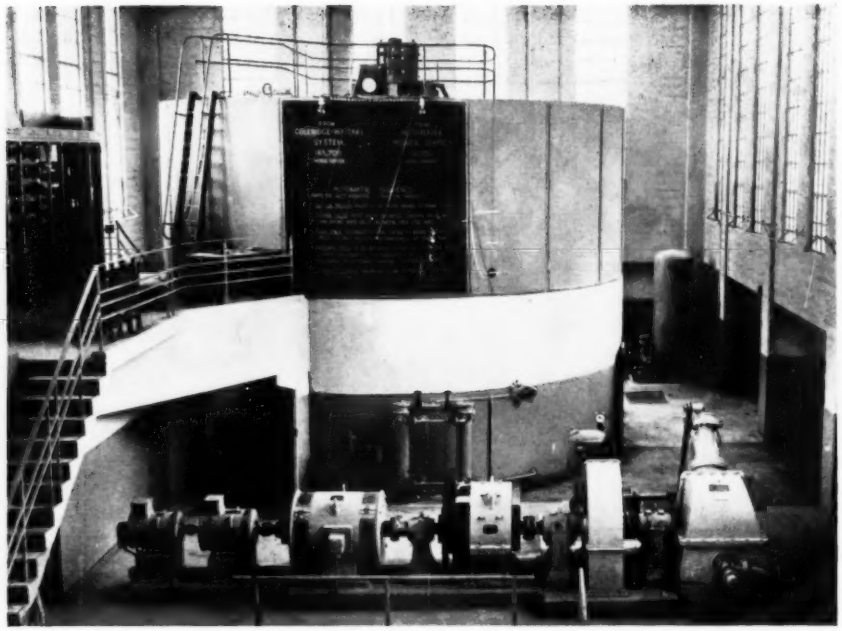


Fig. 4.—The 36,000 b.h.p. completely automatic water turbine driven generating set in Highbank power station, New Zealand.

given by a push button mounted on the control board in the station. This impulse starts up the set that has been chosen as No. 1, and a feature of the control scheme is that, if at any time No. 1 shuts down due to the operation of a protective device, No. 2 automatically starts up to take its place.

Earlstoun and Carsfad, two of the five stations that comprise the Galloway scheme, are completely automatic, under supervisory control from Glenlee. Each contains two vertical-shaft units of 6,500 kW. Although the pipelines are fairly long, there are no turbine inlet valves, the water being cut off by the sluice gates at the intake. The pipeline has to be emptied by the draining away of the water through the cooling systems and by the very small leakage past the closed turbine guide vanes, with the result that it is a considerable time before a shut down can be regarded as complete.

The Highbank Power Station in the South Island of New Zealand contains a single automatic unit rated at 25,200 kW. There is also a 300 b.h.p. auxiliary turbine driving an 80 kW alternator and stand-by exciters for the main unit. A system of supervisory control enables a distant operator to perform the following operations :

Start and stop the unit.
Close and open the main circuit-breaker.
Raise and lower speed (or load).
Raise and lower the setting of the automatic voltage regulator.
Cut in and out load-control gear.

The starting and stopping sequences deal with the main and auxiliary sets as a single entity. Thus, a single starting impulse causes the auxiliary set to run up, and when it is supplying power for the auxiliary motors of the main unit the starting of the latter proceeds without interruption. The load-control gear referred to is operated by a float switch controlled by the forebay level. Thus, although supervisory control may be exercised if desired, the station may also operate fully automatically, once the starting impulse has been given, and carry load to an extent determined by the water available.

Two stations in Australia, the Wyangala Station in New South Wales and Kiewa No. 3 Station in Victoria, are similar in that the generating units are automatic, and have on occasion to operate as synchronous condensers. The change over to condenser running is however carried out manually. Kiewa is similar to Highbank in being arranged for a degree of supervisory control, but there is no automatic control

of load according to water level, and the auxiliary set is not automatic. The station has two automatic main units of 12,000 kW each. The Wyangala Station contains one 6,000 kW unit.

Conclusion.

It has not been possible, within the limits of this article, to make more than a brief survey of what is a very comprehensive subject. A few circuit details have been referred to, because they are of special interest or because they are peculiar to the control of water-turbine driven sets.

The possibility for variations in the degree and method of automatic control is immense and it is probable that every installation made differs in some respect of control from every other one. This is not because manufacturers do not wish to standardise equipment and circuits, but because of the differing requirements of individual schemes. The English Electric Company's engineers have had a wide and varied experience in this field, and are well qualified to solve any of the problems that are likely to arise.

Stud Welding Development and Application

By A. H. BENT, M.Inst.W., A.M.I.E.E., Sales and Contracts Manager, Welding Equipment Section, Stafford.

This article is based on the paper read by the author before the Institute of Welding at the Convention held in October, 1947, in connection with the Marine and Shipbuilding Exhibition. The paper was published in the October Transactions of the Institute, whose kind permission to reprint it in this Journal is acknowledged with appreciation. The welding technique outlined and the data given in the article relate in particular to the rectified A.C. type of equipment described.

The requirements for efficiently and economically fixing studs to a plate by arc-welding may be summarised thus :—

(1) The studs must be exactly positioned and welded vertically to the plate.

(2) The joint between stud and plate must be homogeneous.

(3) The mechanical strength of the weld must be at least equal to that of the stud or plate material.

(4) The operation must be rapid to be economical, and designed so as to permit the welding of several studs per minute.

(5) The welding equipment should be suitable for operation by semi-skilled labour, under the usual shop supervision in order to ensure that the instructions issued by the manufacturers of the equipment are carried out ; and

(6) The studs must be dry, clean, and free from grease. The work plate must also be clean and free from scale, oil, paint or rust.

The whole of the equipment must be designed on robust lines for operation in shipyards or in other outdoor constructional work, as well as in the shops of heavy and light industries.

The Rectified A.C. Equipment.

The rectified A.C. stud welding equipment as developed by The English Electric Company (see Fig. 1) is designed to operate from the secondary side of a standard multi-operator, 3-phase arc welding transformer, such a transformer often being available on site. The secondary of this unit is connected by short leads to a 3-phase oil-immersed static rectifier. The rectifier tank also contains the source of supply of 50 volts D.C. for operating the auxiliaries. A second unit, which is mounted on wheels, comprises the current control regulator and the timing device.

Equipments have been developed in America both of the transformer type, using alternating current in the weld, and for direct current using a motor-driven generator as a source of energy. In general, these equipments are fundamentally similar to the transformer equipment which is here described, but with one essential difference. In the American equipments the gun tool used creates an arc by retracting the stud from the metal, whereas with the equipment here described the arc is created by the fusing of a pip at the base of the stud.

The stud is held against the plate by means of the tripod legs on the gun tool, and when the pip is fused by the passage of the welding current the stud is held in suspension allowing arcing to take place for a pre-determined time, at the end of which period the stud is plunged into the molten pool. The complete operation takes less than one second. The plunging of the stud forces any surplus metal from the pool and this metal forms into a collar contained by a ferrule.

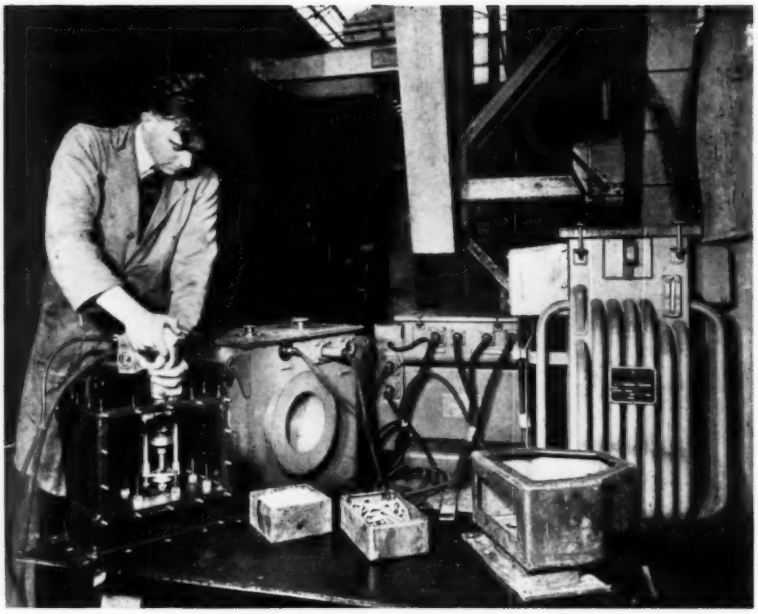


Fig. 1.—Complete large rectified A.C. (D.C.) stud welding equipment capable of welding studs from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. diameter.

The collar metal may, if necessary, be removed by means of a hollow milling cutter without impairing the strength of the weld. In the tool a combined flash damper and ferrule locater is incorporated, thus eliminating all external arc flash and splatter.

The tool is operated by means of a trigger switch and once the switch is closed the remainder of the operation is purely automatic and controlled by a motor-driven camshaft timing device. The current required for a given size of stud is obtained by selective adjustment of a rotary tapping switch on the current regulator, and the necessary timing for this operation is also easily pre-set by means of a rotary handle on the timing mechanism.

The large equipment shown in Fig. 1 is capable of dealing with studs up to $\frac{3}{4}$ in. diameter and with a minimum size of $\frac{1}{4}$ in. diameter, but it is obvious that there must be a field for a smaller type of equipment in the lighter industries. To this end a modified equipment has been produced (Fig. 2) which will permit the welding of studs having a range of 2 B.A. up to $\frac{3}{8}$ in. diameter. In this case the plant is again a rectified A.C. transformer equipment, but is suitable for connecting to a single-phase supply and employs only two ignitrons for rectification. Generally, the principle of operation is the same, but, of course, the plant has not the capacity of the larger one previously described.

This equipment is particularly useful for repetition work with small studs or pins such as those used in lagging materials on boiler work, etc., and for mass production in light metal work. Often with these smaller pins no ferrule is required at the base of the stud and a high speed of operation can be obtained, probably up to 10 studs per minute. One particularly interesting feature of this plant is the fact that no primary contactors are employed, as the ignitrons not only rectify the alternating current to direct current for welding, but also act as a primary contactor or isolator.

A modified form of this plant is also manu-

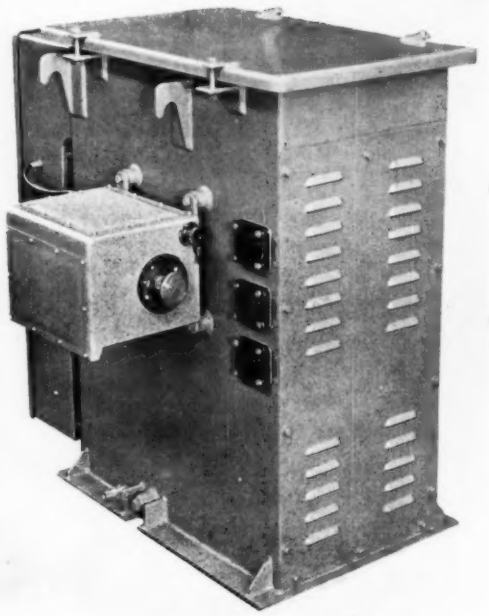


Fig. 2.—Small rectified A.C. stud welding equipment for studs up to $\frac{3}{8}$ in. diameter.

factured with the current regulator and timer separate from the supply transformer, this being particularly interesting from the point of view of use in shipyards, where the main unit at 400 volts is located on shore and the regulators at the lower voltage can be located on the ship and can be used for fixing the studs for the ship's wiring systems, etc. Thousands of these studs are required in a normal size ship.

A further feature of this latter plant is that it can be arranged for two operators by the inclusion of suitable isolators on the secondary side, that is, one transformer can supply two welding regulators arranged so that they do not operate simultaneously.

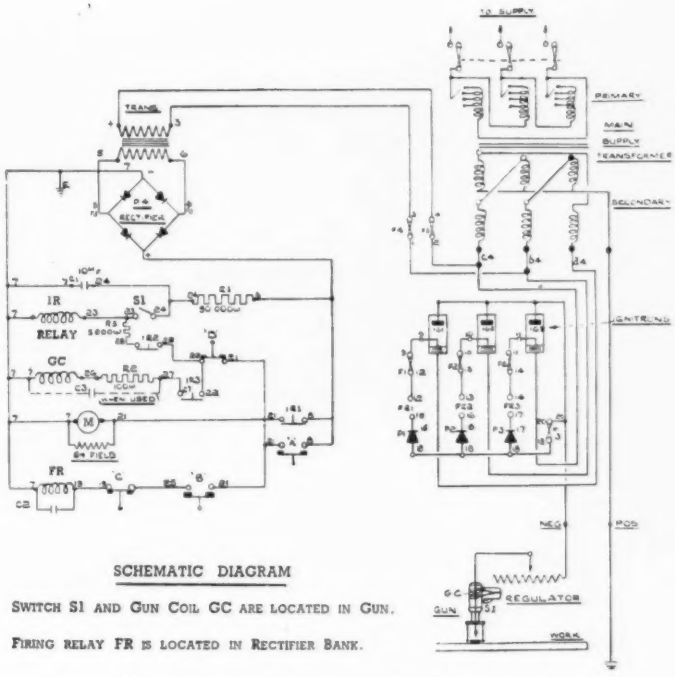


Fig. 3.—Diagram of typical rectified A.C. stud welding equipment.

Operation.

Fig. 3 shows the diagram of a typical 3-phase rectified A.C. stud welding equipment and, without going too deeply into the technical aspects of the control, brief mention is now made of how the equipment operates.

The main transformer has a delta primary, with interstar on the secondary side giving a power supply at approximately 100 volts, phase to neutral. The secondary is connected direct to the ignitron bank, and from the outgoing side of the ignitron bank the direct current is passed through the welding regulator, and thereon through the gun to the work. A source of D.C. supply for operating the timing mechanism is obtained through an auxiliary transformer connected across the secondary side of the main unit, the secondary side of the auxiliary transformer being connected to a bank of small rectifiers. A further source of D.C. supply is obtained through a bank of selenium rectifiers to feed the ignitor circuit of the ignitrons. All auxiliary equipment is located in chambers on the main equipment and is amply protected from electrical or physical damage.

On closing the gun switch (S1), a source of supply is obtained from the condenser from which current passes through a P.O. relay (I.R.). This is a 3-pole relay.

On the camshaft-motor speed-reduction shaft there are four switch-operating cams, and the motor (M) now rotating closes a cam-switch, which ensures that the motor performs its function of causing one complete rotation of the camshaft. Another of the cam-switches closes to give a D.C. supply to the ignitor pins on the ignitron bank through 3-pole relay (F.R.). This causes the ignitrons to function, passing the direct current through the stud, the time of operation depending upon the setting of the timing equipment. A further cam-switch now opens and cuts off the supply to the gun retaining coil (G.C.) which releases the stud under spring pressure and permits it to plunge into the molten metal to form the weld.

The last cam-switch now opens, cutting off the supply to the firing relay (F.R.), i.e., to the ignitors on the ignitron bank, which cuts off the flow of current. The operation is now complete with the exception that the first cam-switch opens so as to re-set the other cams for the next operation.

Applications.

It can be said generally that, where it is required to use steel studs or bolts in normal engineering manufacture up to $\frac{3}{4}$ in. diameter, there is a possible application for stud welding equipment. The process has proved itself in

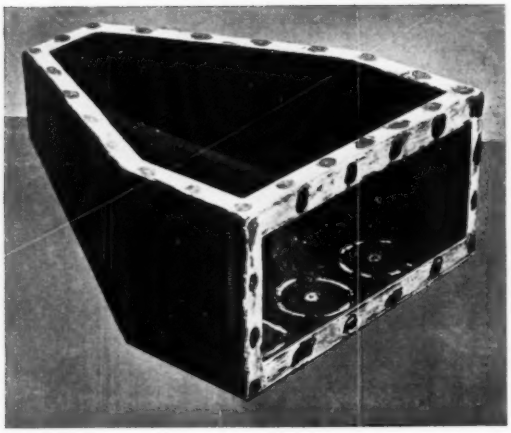


Fig. 4.—Trifurcating box marked off ready for stud welding.

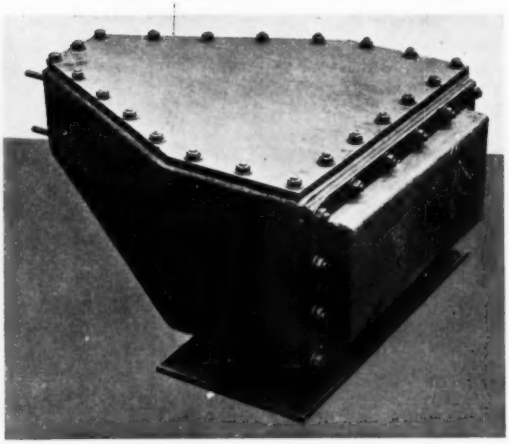


Fig. 6.—Assembled trifurcating box.

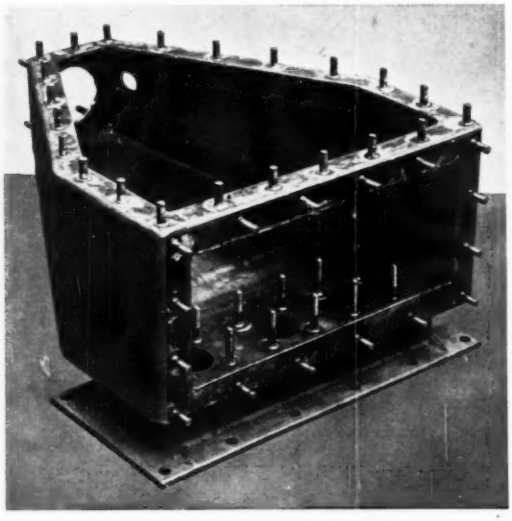


Fig. 5.—Trifurcating box after stud welding.

service. For certain work in connection with boilers the process described has been approved by one of the leading approval bodies in this country. There should be no doubt whatsoever as to the performance of the plant and its ability to make a sound weld, providing correct procedure is carried out.

In many applications the older method was to bolt through the casing and to use some means of preventing oil or water leakage through the bolt holes. The bolt heads were sometimes welded to prevent leakage. Such sealing is eliminated by the use of stud welding. (See Figs. 4, 5 and 6.)

Usually the job is marked off and centre punched for welding. Alternatively, a template is used and the stud position marked-off by the use of a drill. The centre punch or drill hole in the metal should not be made too deep as this reduces the effective length of the spigot at the end of the stud, which, of course, results in reducing the arc length and hence the arc energy in the weld, which may reduce the efficiency of the weld.

One interesting point of stud welding is that the heat is very localised and during the short time which is required to make the weld, distortion of even thin plates is practically negligible. Where in the old system the plate was drilled and bolts were passed through and arc welded, distortion could easily take place.

Stud welding can be carried out in the vertical, horizontal, or overhead positions, but obviously, as in other forms of arc welding, it should preferably be carried out in the downhand position, i.e., the true vertical. However, studs up to $\frac{5}{8}$ in. diameter can be welded in the horizontal position, i.e., with the plate in the vertical plane, and research and development have taken place in order to ensure that a very sound weld is made even with studs of so large a diameter.

Gravitation plays an important part in stud welding in any position and the effect is particularly pronounced in welding the larger diameter studs horizontally. The molten metal tends to run downwards and it is necessary to have a correctly designed refractory ferrule to form a complete collar of molten metal round the base of the stud. Overhead stud welding does not present such great difficulties as welding in the horizontal.

There are a great many fields in engineering where stud welding could be applied in the light

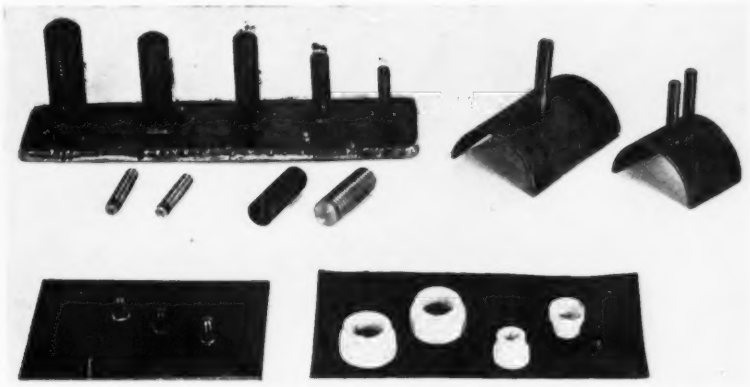


Fig. 7.—Samples of studs and ferrules up to $\frac{3}{4}$ in. diameter.

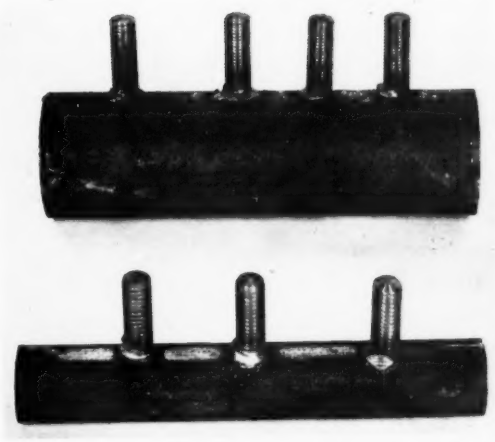


Fig. 8.—Studs $\frac{1}{2}$ in. diameter welded to tubes.

and the heavy industries. For instance, on light plates stud welding could be used in place of riveting. For this application a hole is drilled in the top plate and the stud is welded through this hole to the bottom plate, the stud metal filling in the hole and so completely welding the two plates together.

Plates could also be welded to tubular sections by welding a stud through the thin plate and penetrating through the plate on to the tube, thus effectively welding the two sections together.

Small-diameter welded pegs can be used for locating lagging material on boilers, etc., and in this case it is possible that the ferrule will not be required. Steel studs can be quite easily welded to stainless steel and, of course, it is well-known that steel studs can be welded to high-tensile steels.

Stud welding is now used extensively in shipyards, particularly for deck welding, i.e., for locating the wooden baulks to the steel deck. Originally the studs were welded direct through the wooden baulks to the deck by the use of a

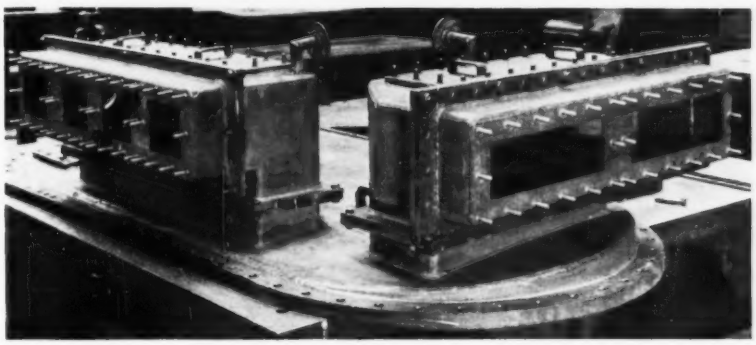


Fig. 9.—Studs welded to transformer cable and interconnection boxes.

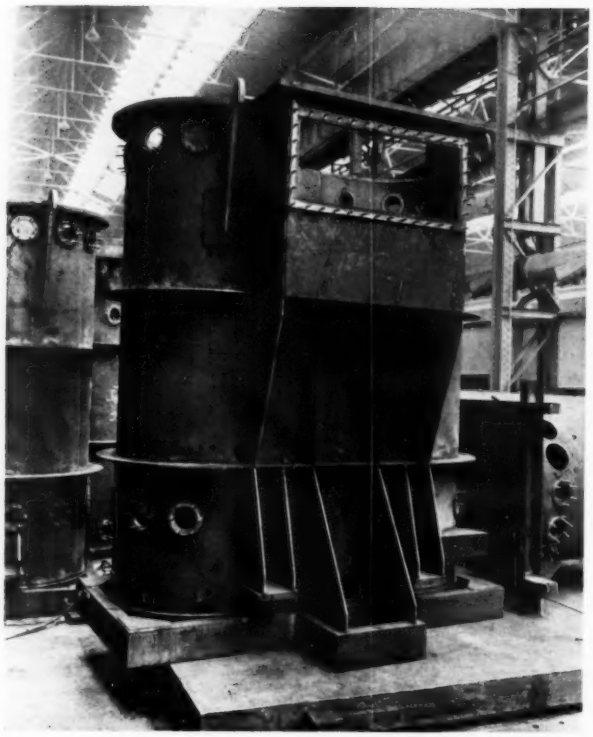


Fig. 10.—Studs welded to transformer tap-changer pocket and radiator connections.

special gun tool adaptor, which centralises the stud through the hole in the wooden baulk. This method of welding presented difficulties, some of which were: (1) charring of the wood causing carbon inclusion in the weld-metal ; (2) probable fouling of the studs in the small baulk clearance hole ; and (3) no anti-corrosive paint could be added to the deck and stud after welding. Modern practice is to mark off positions for the studs to be welded, weld the studs, apply anti-corrosive paint and then fit the wooden baulks.

This application is of particular interest as in the older method the deck was either drilled and screwed or drilled using bolts to locate the wood, and this involved either arc welding on the underside or caulking to prevent water leaking through to the under-side of the deck.

Studs and Welding Details.

The studs used on the equipment are of special design as mentioned earlier, some samples of studs and ferrules being shown in Figs. 7 and 8. It is also important that the quality of the steel used in the studs is controlled, permitting only a fairly low sulphur and phosphorus content with normal carbon content, equivalent to the core wire of any good coated steel electrode used in the process of arc welding.

It is advisable to obtain such studs from the manufacturers who carefully control this steel, but the following is a typical specification of the metallurgical requirements of the steel : carbon .08—13%, silicon 0.10% max., manganese 0.5%, sulphur 0.05%, phosphorus 0.05%.

Certain non-ferrous materials can be used, as for example, Admiralty brass, and steel studs can be welded quite easily to stainless steel. Studs can be welded to almost any type of steel, including armour plate to thicknesses ranging from 16 gauge upwards, but it must be remembered that the energy in the arc, although only for a short duration, is of high value and penetration in the parent metal is considerable, so that it is not possible to weld very large studs

Fig. 11.—Stud welding gun tool in use on transformer tank.

to thin gauge materials unless very special precautions are taken and then it is problematical. Tests on one of the welding equipments in use gave the following particulars which are typical :

Average tensile breaking load—approximately 30 tons per sq. in.

Position of break—in the stud material.

Exhaustive investigations into the metallurgical strength of the stud weld have been carried out by plant manufacturers and users, the results being highly satisfactory, as in arc welding generally, the weld metal being sound, free from porosity and inclusions, with good penetration.

In order to obtain a comparison of times taken in the various methods used for fixing studs and bolts to plates, a series of tests was made in the earlier stages of stud welding. The time taken for stud welding on the whole was much less than that required for any other form of fixing. With further experience the time now required to stud weld has been greatly reduced.

Figs. 9 and 10 are typical examples of stud welding used in heavy industry, and Fig. 11 shows a stud welding gun in use.

Electrical Plant for Tyre Manufacture.

By J. H. M. SYKES, Associate I.E.E., Publicity Department.

Fig. 1.—Factory approach, India Tyre & Rubber Company, Inchinnan.

The manufacture of rubber tyres involves a very high degree of works planning. The processes, in which there is a continuous flow of material subject to carefully controlled heat treatment, must run without interruption, day and night. An extensive system of electric drives—largely applied to individual machines—has been found to be essential. By its aid it is possible to ensure a Works layout in which there is no waste effort, since the machinery can be placed exactly where required by the process planner. There is also complete flexibility to permit the product to be changed or the factory to be extended, and absolute reliability of motive power is combined with economy in operation.

A typical example of British practice in tyre manufacturing is to be found at the India Tyre & Rubber Company's Works at Inchinnan, in Renfrewshire. Established in 1928, this modern factory employs some 2,000 people on a three-shift basis, and its output of over 3,000 tyres a day includes all sizes, from those destined for the humble wheelbarrow, to the largest tractor or bus tyres.

Before giving a brief description of how the electrical engineer meets the problems presented to him by the factory requirements, it may be as well to set out the overall plan for the delivery to the various machine sites of the power which they need for their operation.

Fig. 2.—Two 1,000 kVA and one 250 kVA transformers, and a 6.6 kV oil-filled reactor rated at 4.8% on 3,000 kVA, in one of the three substations.

Energy is brought to the factory in two forms. The first is a bulk supply of electricity from the former Clyde Valley Power Company's mains (now those of the South West Scotland Electricity Board). The second is in the form of the chemical energy in raw coal, which is burnt in the boilers to provide the large quantities of process heat needed at many stages of manufacture.

The Incoming Circuits.

There are three points where electrical power is taken in, these being known as Nos. 1, 2 and 3 Substations. The twin 11,000-volt, 3-phase mains, are brought in to Nos. 1 and 2, while incoming cables, also at 11,000 volts, run between all three sites. If No. 3 Substation is described, it will serve as being typical of all three.

In order to reduce the duty on both the 11,000-volt and 440-volt switchgear, it was decided to instal a reactor at each station, directly connected to the incoming main. These reactors are of the oil-filled type constructed by The English Electric Company, their rating being 4.8 per cent. at 3,000 kVA. In No. 3 Substation, the reactor is installed externally to the Substation, in one of a series of neat brick-built enclosures, the remainder of which are occupied by the step-down transformers, see Fig. 2. A double-float Buchholz protector is provided, the alarm float being connected to a klaxon inside the building. From the reactor the 11 kV incoming supply is taken to a single-busbar, cubicle-type switchboard, comprising four panels of "English Electric" type OLC circuit breakers; one on the incoming side and three on the outgoing. These breakers have overload protection, and are manually operated.

The three step-down transformers are installed externally to the building, two being of 1,000 kVA and one of 250 kVA. These also have Buchholz protection. The two larger transformers feed a 14-panel, 440-volt, 3-phase, switchboard in which "English Electric" type OB3 air-break switches are employed. These are mounted on the face of the panel, and at the rear there is an open-type busbar assembly. Doors in the screens at each end give ample access to the back of the panel for maintenance, while ensuring safety under normal conditions. Each circuit includes a manually-operated isolating switch. An ammeter is also provided. Time-lag overloads are incorporated in the circuit breakers, and for testing purposes the

Fig. 3.—One of the main substations, showing from left to right; end of 11 kV truck type switchboard, "OB" 2-pole D.C. circuit breakers, 250 kW rotary converter, and "OB" 440-volt air-break switchgear.

Fig. 4.—No. 2 Substation, including from left to right, part of 11 kV truck type switchboard, 440-volt oil circuit-breakers, two 250 kW rotary convertors, and the most recent addition, 440-volt "OB" air-break circuit-breakers.

neutral connection (of the majority of circuits) can be broken at a test link mounted on the front of the panel.

The third transformer is of 250 kVA capacity, and feeds a rotary convertor used in supplying part of the Works' load where direct current is needed for speed regulation purposes. Some 770 h.p. of d.c. motors are connected, and these are fed from the rotary convertor mentioned in the description of No. 3 Substation, from two similar machines in No. 1 Substation, and from a 30 kW motor-generator set in No. 2 Substation. All these machines are of "English Electric" manufacture, while the company was also responsible for the direct current air-break circuit breakers, which are installed in a manner generally similar to that employed for the a.c. board.

The No. 3 Substation building fulfills the highest modern specifications for substation design, being of an entirely non-inflammable construction, having ample ventilation, and with the cable troughs sunk in the floor, while there is adequate space for maintenance work, and room for extension.

Distributing the Energy.

The power supply from the three Substations is taken to the various machine bays by means of p.i.l.c.s.w.a. cables, but part of the power is transformed into two further sources of energy —compressed air and hydraulic pressure.

The compressor house which is illustrated in Figs. 5 and 6, has a total of six compressors; two of these being of the high-pressure type delivering 1,000 cubic ft. of air per minute at 250 lb./sq. in., while the remaining four are of the low-pressure type with the same delivery, but at a pressure of 100 lb./sq. in. With one exception, all the motors for this duty were manufactured by the Company, and are of the protected type with rotor resistance starting. The other conversion—that

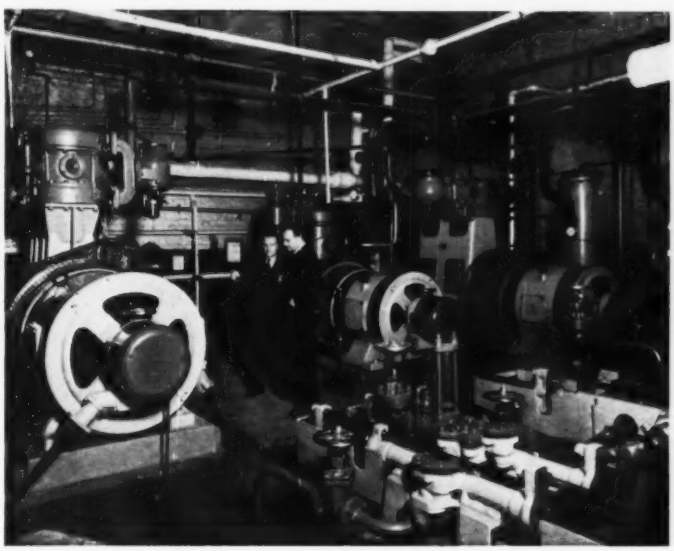


Fig. 5.—The machine room containing high and low pressure air compressors and hydraulic rams. Three of the compressors are shewn, all driven by "English Electric" motors.

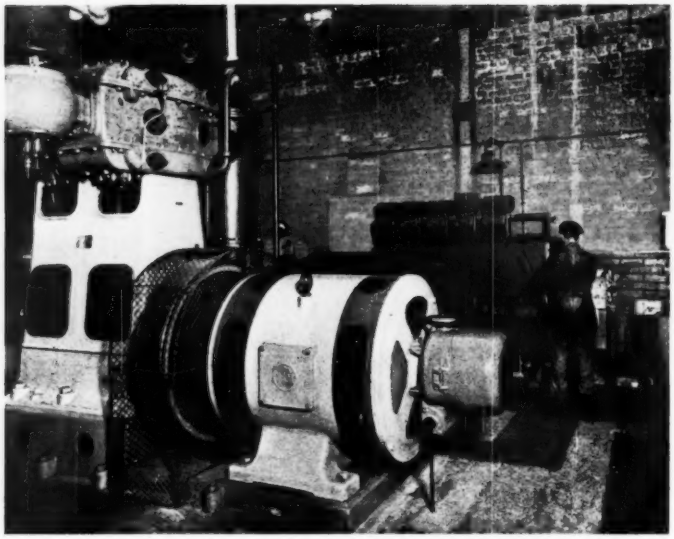


Fig. 6.—Another view of the Machine Room in Fig. 5, showing in the back-ground an "English Electric" Combination Fuse-Switchboard as used for distribution throughout the factory.

into hydraulic power—takes place by means of four motor-driven centrifugal pumps, of which two employ 65 h.p. electric motors, while for the remaining two, the motors are of 38 h.p.

In this building there is also a steam-driven standby generator, of 100 kW capacity. In the event of total failure of the external supply mains, this machine can serve the essential boiler-house stoker motors and certain vital machines in the Works.

The necessary process steam is derived from the burning of coal in three Babcock and Wilcox water-tube boilers, having a total steam capacity of 46,000 lb. of steam an hour, at a pressure of 175 p.s.i. These are fed by chain grate stokers having "English Electric" motor drives, and are installed in a carefully-planned boiler-house, with a single chimney. Automatic coal and ash handling plant is shortly to be fitted.

Thus, there are five main sources of energy to be distributed to all parts of the factory —3-phase a.c. at 440 volts; d.c. at 220-110 volts; compressed air at high and low pressures; hydraulic power; and steam. But, as will be seen above, all except the steam derive their prime source of power from the electric mains—and the steam is dependent on the chain grate stoker drive. Thus, it can be properly said that the whole factory depends on electrical energy for its daily functioning.

The Tyre making Process.

The process of tyre manufacture is carried on as a continuous flow of material, and any interruptions would result in serious losses; thus the electrical plant must be of the highest reliability and must need the minimum of maintenance, since from Sunday night until noon on Saturday in each week the process is continued without a break.

The products are principally, of course, the outer cover and the inner tube; there are a

Fig. 7.—One of the Banbury mixers in which the raw rubber, chemical fillers, etc., are masticated. It is driven by an "English Electric" 440-volt 3-phase synchronous induction motor having two ratings of 250 h.p. at 500 r.p.m. or 500 h.p. at 1,000 r.p.m.

number of ancillary items, including the flap which is fitted to the larger size covers when mounted on flat base rims.

Fig. 8.—The shop in which the tyre casings are assembled. In the right foreground is a bias cutter driven by a 5 h.p. "English Electric" motor, in which strips of rubber-impregnated fabric are cut on the bias for assembly later into tyre casings.

On entering the tyre works one first sees the preparation of the fabric, which forms the basis of the tyre. Large vertical impregnating machines carry rolls either of natural Egyptian cotton, or of rayon, which are prepared first by dipping in a suitable rubber compound in liquid form, and then dried. Impregnating machines are driven by 5 h.p. motors. At the same time, the raw rubber, as imported from Malaya, is being mixed in a number of Banbury mixers. Here the rubber is carefully weighed, and to each bin, containing a measured quantity, is added a number of other chemicals, in which sulphur and carbon black are prominent. The Banbury mixers are driven by 500 h.p. "English Electric" motors and a typical motor (see Fig. 7) is of the two-speed type, developing 250 h.p. at 500 r.p.m., and 500 h.p. at 1,000 r.p.m. Control is automatic through contactor gear in sealed sheet-steel cubicles adjacent to the motor, and dynamic braking is provided to bring the whole mill shaft quickly to a standstill in an emergency. The motor is of slip ring, protected type, with rectifier equipment providing the necessary direct current for braking.

Some of the motors on the Banbury mixers, particularly those in close proximity to the carbon black mixing stage, are equipped with external ventilating ducts leading to a fan which draws in fresh air from outside the building. Thus the very fine carbon dust is prevented from entering the windings.

Once the rubber has passed through the Banbury mixer, it is passed to a long series of mills, where it is then forced between water-cooled steel rollers, further to improve its homogeneity. It is manually removed from the mills and placed on a travelling conveyor, where cooling takes place, and where it is sprayed with soap-stone solution.

Further calender mills are employed at the point where the rubber and the prepared fabric are brought together. Rubber strip is fed into the top nip of a three-bowl calender, and is flattened out uniformly across its width. The prepared fabric is fed into the second nip, and the thin layer of rubber is transferred to its surfaces by passing at least twice through the calender under conditions of considerable heat and great pressure. The motor used to drive the calenders is of 100 h.p., and since complete speed variation from zero speed to the full rate of 1,200 r.p.m. is required, it is fed by direct current.

The fabric is next cooled by being passed over a series of cooling drums, and is then taken to the bias cutter. To ensure that the tyre casing has the maximum strength possible, alternate layers of the plies of which it is composed have the run of the threads in the fabric crossing approximately at right angles. To cut shaped pieces of the rubberised fabric in a manner suitable for this lay, bias cutters are employed, in which the material is brought over automatic tensioning rollers to a cutting board. In one form of bias cutter, a horizontal clamp is brought down across the fabric and cut with a travelling knife at the requisite angle, by the action of solenoids which are energised by auxiliary switches actuated by the passage of the material itself.

In another form of cutter the material is unrolled on a horizontal cutting table, and an automatic traverser causes a cutting wheel to run across it, when the passage of the correct length of fabric has actuated the auxiliary switches controlling the cutter.

The fabric plies, which are to form the basis of the tyre cover, are made into bands or pockets and brought to the tyre building machines. The requisite number of pockets are built up, one on top of the other, and pressed together by re-

volving rollers bearing on the cylindrical drum on which the tyre is being built up.

A specially compounded rubber is used for the manufacture of the tread, but before being brought to the extruding machine which forms it into shape, it is further necessary to pass it through mill rolls to make it workable. From these it is passed to the extruder, where the rubber strip is forced by screw pressure between dies, which form it into the tread section required.

The extruded tread passes on a conveyor belt to a cooling bath, and after cooling is cut off automatically by a water-cooled circular knife. In the course of this process it is weighed to ensure that the correct amount of rubber is employed. The extruder is driven by a 100 h.p. d.c. motor to allow for variable speed, since differing tread lengths and sections require varying process speeds. The conveyor drives are provided with 10 h.p. and 1 h.p. motors.

The treads are then brought to the cover-building line, and are assembled on to the plies, again being secured by the pressure of rollers against the tyre assembly on its cylindrical drum.

Tyre Building.

During the operation of tyre building the beads are placed in position. This item is composed of a number of strands of coppered-steel piano wire, which are assembled through cleaning dies, and are then coated with hot viscous rubber. The requisite length is cut off automatically. Several turns of this composite material are used to form one bead, the ends being bound up with rubberised tape. Fabric wrapping is added to the completed bead to hold the wires in position. This unit is encased in a strip of fabric which serves to anchor the bead in the correct position in the plies of the casing.

The drive to the tyre-building machines is one which makes a heavy demand on the electrical equipment with which it is associated. The speed has to be infinitely variable, since the operator must be able to apply the external pressure rollers at first slowly, gently and selectively, as he places the pockets and the tread in position, and later with greater force and at higher speed. Reversing is also required, and inching facilities are needed in both directions. For this purpose 3½ h.p. d.c. machines are used, and a nearby panel houses the contactors which carry out the operations initiated by conveniently placed foot-pedal switches. The machines are compound wound, and operate either from 220 volts (across the outer conductors of the supply mains) or from 110 volts (from one outer to the middle wire).

The tyre is next shaped up on a vacuum press. A horizontal receptacle takes the tyre in the form in which it is built, shapes the cover, and the "air bag," which is an extremely stout inner tube, is inserted during this operation.

The next processes are those of vulcanization. The cover, complete with its air bag, is inserted in a mould. This comprises top and bottom halves each bearing the peculiar indentations for each type of tyre tread, together with the name, details of size and type and other particulars, embossed on the inside surfaces. The mould is taken on a gravity runway to the vulcanising autoclaves. These are steamheated cylinders, sunk in the ground, with hydraulic rams to carry the moulds. A number of moulds are placed in this cylinder by the aid of a pneumatic hoist, and as each one is added, connection is made to the tyre valve on the air bag, through a jointed pipe rising through the centre. When the autoclave is filled, the top cover is clamped down, hydraulic pressure is applied to the ram, and air or steam admitted to the air bag.

From that point onwards elecrical instruments in the form of pyrometers and timing devices control the vulcanising process. Steam heat is turned on to the outside of the moulds at a given exact temperature, and the pressure in the air bags is also

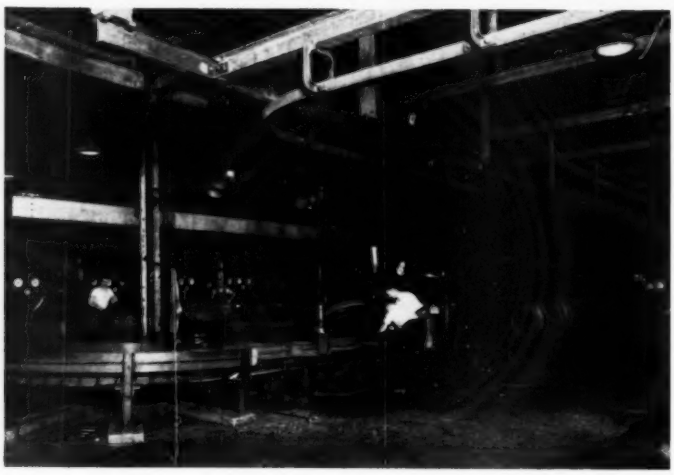


Fig. 9.—Tyre casings are removed from the moulds after vulcanising, and further casings are brought by the conveyor (right), driven by "English Electric" motors, to replace them in the moulds which move again on the conveyor to the vulcanising autoclaves.

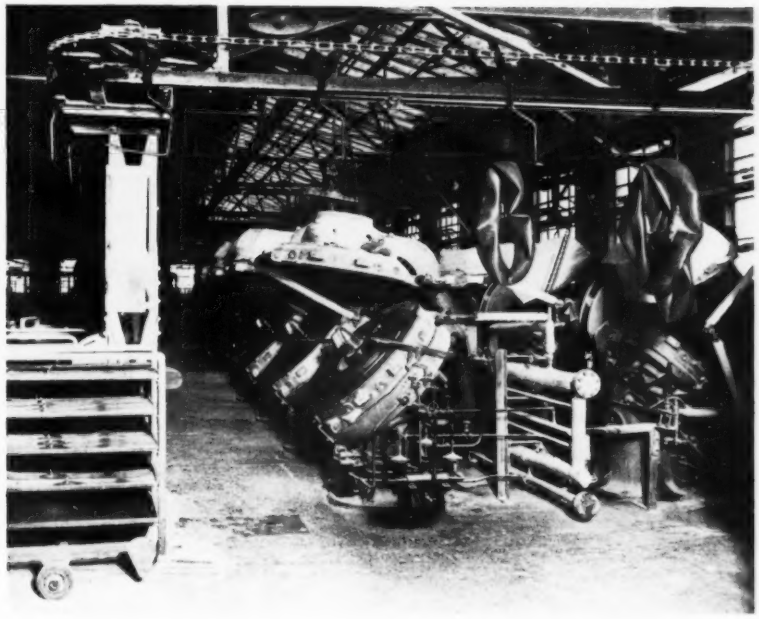


Fig. 10.—Automatic vulcanizers in tube shop, with tubes in position, the lids having opened automatically after correct heat and time applications. Electrical control is used for the pneumatic valves.

regulated from the same control panels. The time taken for vulcanization varies with the size of the tyre, and the steam pressure and the air supply are automatically turned off when the vulcanization is complete. Recording instruments give a permanent record of the timing, temperatures, air pressures, and so on, for each batch. The lid of the autoclave is then opened and the moulds are removed one by one by means of electric and pneumatic hoists situated on convenient runways above the autoclave. The tyre is then very nearly in its final form, and bears the well-known trade design, while the rubber has been toughened and the whole of the plies, the tread, and the beads have all been vulcanized together to form one completely homogeneous body.

The air bag is removed by a special machine, considerable force having to be applied. A hook is forced into the cover and grips the air bag, the tyre meanwhile being held in a suitable frame. A pneumatic thruster pulls the hook and wrenches the air bag from the cover. All that is finally necessary is to inspect and paint the cover, and it is ready to go into stock.

The Inner Tube.

The inner tube is made in a separate division of the Works. Rubber compound from the Banbury mixers is used on separate blending mills, where it is made ready after repeated passages through the mills for passing to the extruding machine. Here the rubber compound is forced out of the extrusion dies by the action of a screw, and, through the centre of the nozzle, a fine stream of french chalk is constantly blown, thus covering the inside of the tube as it is formed.

The long continuous length of extruded material is specially weighed and run through a trough of cold water. The extruded tube is carried forward on a conveyor belt and is cut off to the required length by an electrically-heated knife. At the same time a die on which is cut the appropriate lettering is brought down on the tube after having been inked by a roller and the name, size, date, and other particulars are indelibly stamped on each length. The cut lengths are then removed by hand.

The tube lengths are then dusted with chalk, and it may be of interest in passing to note that the electrical gear which operates the extrusion machine and its ancillary devices has to be protected against this dust. The windings must be guarded against the entry of this material, which would rapidly choke up the interstices, and so cause trouble.

The next process is to join the two ends of the

tube, and to insert the valve. The jointing process is very simple. The operative, after cutting with a hot knife to the required length, takes the two ends and having first pressed them together by hand, inserts them in a pneumatically-operated sealing press, which forces the ends together under great pressure. Prior to this sequence of operations a hole is drilled in the tube, and the valve, with its surrounding flap of rubber, is inserted and stitched by hand on to the still-soft rubber tube.

The inner tubes are now ready for final vulcanizing, and here a series of steam-heated vulcanizing tube pots or moulds lie lengthwise down the workshop, shown in Fig. 10, and are operated entirely automatically. The lid is opened by pneumatic means, the tube is placed in the bottom half of the mould, which is made exactly to shape, and a flexible air hose is connected to the valve of the tube. The top half of the mould is closed. Timing apparatus then takes charge and air pressure is automatically turned on through the valve to press the tube into close contact with the mould. After a predetermined period the air pressure is cut off and the mould opens itself, leaving the operative to remove the vulcanized tube. The next process is to test it for leaks and this is done in a tank of water, with a pneumatically-operated plunger to hold the tube under the surface while the inspector watches for bubbles. Since the mere removal of the valve would not empty the tube of its air content sufficiently to enable it to be packed flat, it is automatically exhausted of air by the application of a vacuum, which leaves the tube completely flat ready for inspection and packing.

In all some 715 motors are used in the Factory and the management have largely standardised on "English Electric" products both for the motors and for the distribution gear which exists in every shop. For this latter purpose, metalclad combination fuse-switchgear has been used, incorporating high-rupturing-capacity fuses.

The maximum demand on the Factory as a whole is approximately 3,900 kW, while the installed capacity is of the order of 9,750 kVA. A high load factor of approximately 70 per cent. has been achieved by careful planning of the power drives which operate, of course, for 24 hours a day, for 5½ days in each week.

In view of the varied atmospheres which exist in the Works, almost every type of motor enclosure is employed. The open protected type is mainly used, but some motors are totally enclosed. In the cement mixing house, where agitators are employed to mix up the volatile spirits used in certain stages of the manufacture with rubber and chemical solvents, the atmosphere is such that flame-proof motors have to be used.

As will have been noted from the description of the tyre manufacturing process briefly detailed above, each operation is dependent on the flow of material from the preceding section of the plant. Therefore any stoppage would result not only in a complete holdup, but, if accompanied by the cooling of plastic rubber in the mills and other machines, would involve serious financial loss while the rubber was extricated. To ensure that this does not happen, not only must the right electrical plant be chosen for each duty, but maintenance problems must be dealt with on a very comprehensive basis. The maintenance staff has access to the plant only at week-ends, but without exception all large motors are cleaned out every seven days, and, where brushgear exists, it is overhauled. If this were not done, there is, for instance, a possibility that the carbon black, used in the mixing processes, might penetrate and form contact paths, which would subsequently give rise to flashovers. The very heavy duty imposed on contactor gear, starters, and the like, means that it is desirable to inspect all these items every week-end, and although it is not found necessary to replace contacts frequently, this inspection provides that should a contact be found to be pitting, or showing signs of wear, it is immediately replaced before trouble can arise.

Fig. 11.—"English Electric" heavy duty cooking equipment in the canteen kitchen, showing a two-pan fish frier on the right and a boiling table on the left.

Spare motors are carried, and spare armatures are provided for some of the larger items. Twice a year all oil circuit breakers are examined, and the oil changed if necessary. Oil samples are taken from the top and bottom of all transformers and reactors, and are examined to ensure that neither oxidisation nor sludging has affected the electrical qualities of the oil.

The Works Canteen has to cater for a continuous service of meals throughout the 24 hours, and thus the name " heavy duty " applied to the kitchen equipment —the major items of which have been supplied by The English Electric Company—is no misnomer. The large and airy kitchen adjacent to the dining hall contains the most modern types of food handling appliances, and includes a two-pan fish fryer, a boiling table, a double-oven range, and a cabinet roasting oven.

We are indebted to the India Tyre & Rubber Company, Limited, and in particular to Mr. F. Allison, their Chief Electrical Engineer, for the facilities they accorded for the preparation of this article, and for their permission to take the photographs which accompany it.

Fig. 12.—Canteen kitchen showing double oven range and cabinet roasting oven.

The Dynamic Re-Conditioning of Corroded Aero-Engines

(Using the Napier Engine Servicing Trolley)

A Report from The Napier Technical Publications Department.

Introduction.

It may not be inappropriate to define briefly the particular meaning of the word corrosion as implied by its use in the following article.

Corrosion is a chemical action produced on a material as a result of its exposure to hostile chemical elements or compounds, resulting in the deterioration of that material; the most generally encountered form of this occurring in metals, which are reduced to their respective oxides or kindred salts by exposure to unstable oxygen.

Metals may also be corroded by active alkalis, by certain acids (collectively known as corrosive acids), by inter-action between unlike metals in contact, and by structural failure of lubricants.

The term applied to all oxygen-produced deterioration is oxidisation and under this condition the rate of spread is very rapid—the vulnerability of the metal increasing more rapidly than the rate of increase of the corroded matter. With acid corrosion this action is even more marked and complete destruction may take place in only a few hours, but corrosion arising from lubricant failure ceases with removal of the deficient oil or grease.

To prevent deterioration by corrosion when not in regular use, most metallic equipment requires treatment by some form of rust-inhibiting process before being set aside or put to store. If the item is of such a nature that all exposed metal surfaces are accessible this is merely a matter of coating them with a film of inhibiting fluid or, where conditions demand it, of completely sealing the item from atmosphere in a " cocoon " formed by an enshrouding envelope of sprayable plastic paint or one of the many other special

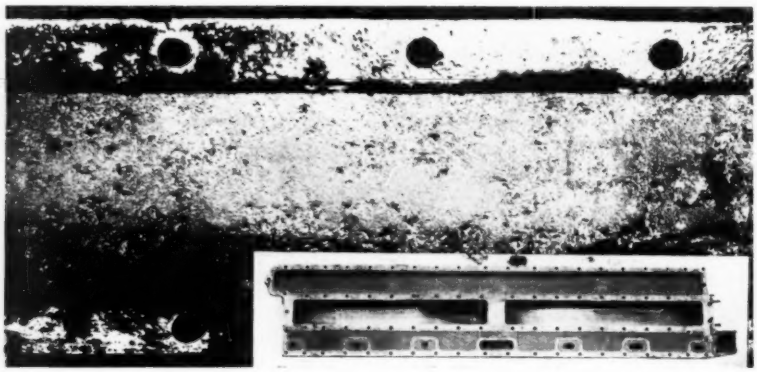


Fig. 1.—Corroded manifolds showing deep pitting over a large area.

compounds that have been developed for this purpose. By selecting the optimum treatment for the job, it is, in fact, comparatively easy to prevent corrosion in simple equipment over comparatively long periods of storage.

Corrosion of Aero-engines in Storage.

With more complicated items such as aero-engines, however, the direct application of the inhibitor on to all susceptible surfaces becomes impossible without extensive dismantling. From this point onwards the process of inhibiting consists of two separate operations, external and internal inhibiting.

External surfaces, being accessible, as explained above, present no problem, but the treatment of internal surfaces has been the subject of intense research over many years with only limited success, and engines are still found to be corroded, not infrequently to the point of seizure, despite application of recognised inhibiting techniques. Throughout the war years, when engines were rarely stored for any length of time, the number of engines destroyed by rust was comparatively small; now, however, when large stocks of engines are held in store for relatively long periods, widespread damage by internal corrosion is a matter for serious concern. Engines found to be corroded have to be categorised "Unserviceable" until completely dismantled and repaired; a costly process at the best of times and a formidable task where man-power in the maintenance hangars is in short supply. In this connection it is interesting to note that ten new inhibiting compounds were announced by American authorities in the early part of this year, and the June issue of "Machinery" contains details of two more.

The Technical Problem.

The reconditioning and inhibiting methods described herein will be more readily understood if the technical problem involved is first defined, especially as the emergence of a corrosion problem with the present day use of stainless steel and rust-resistant alloys might be thought to imply a design failure in terms of metallurgy or choice of lubricants, or perhaps both. In point of fact, neither is the case, for the problem arises from two factors inherent in the basic principles of engine construction. The first is that corrosive-resistant alloys are relatively soft and only suitable for lightly stressed parts; hence the majority of the working parts such as crankshafts, liners, sleeves and gears, must be made of steel. As the stainless steels are both costly and in short supply the normal, more corrosion-susceptible, steels must be used for the bulk of the working parts. Further, in high-performance engines of the Napier "Sabre" type, it is very desirable to use the hardest steels obtainable for sleeves and other parts subjected to heavy surface loading. Unfortunately these are the parts most readily damaged by corrosion and the very hard steels (particularly the nitrided group) are highly susceptible to it. Thus, the engine designer must choose between minimum wear on vital parts in operation and maximum resistance to corrosion when in store. The second factor of the corrosion problem arises from the first, which has already been touched upon; the parts which have been mentioned as being highly susceptible to corrosion are also internal parts—most of which are totally enclosed in the assembled engines.

To summarise, the problem of preventing corrosion in stored aero-engines is essentially one of passing an effective inhibitor on to the surface of internal parts, most of which are necessarily made of ferrous metals, of which the rust resistance is relatively low.

Consideration can now be given to the limitations of current inhibiting methods and the inter-related problem of reconditioning engines already affected through failures of the preventive methods themselves or because they were incorrectly applied.

Static Inhibiting.

This was the first rust-preventive method to be devised—and in contrast to the quite prohibitive cost of completely dismantling the engine

it involves no dismantling at all, very little work and a minimum of time ; a spray-gun is the only special equipment required. Originally the process consisted of coating the cylinder walls and valve-gear with lubricating oil and turning the engine through several revolutions by hand. Later, special inhibiting fluids were introduced for protecting these parts, while the sump was filled with a special storage oil containing inhibiting additives—with a view to protecting the bearings and other lubricated parts after circulation. As the fluid circulation is very much limited by hand-turning however, static inhibiting is only partially effective in preventing internal corrosion and many engines treated by this method have subsequently suffered heavy damage from corrosion.

Circulation by Motoring.

If, however, instead of being turned by hand, engines are " motored " by external power, the storage oil is circulated much more thoroughly, but even then the inhibitor in the cylinder fails to penetrate past the piston. Further, motoring by external power, as with hand-turning, has the disadvantage that the temperature of the engine is not raised and condensates are not expelled from the interior. Despite the more costly equipment required, " motoring " did not solve the problem and static inhibiting, with all its known limitations, was, until recently, the most widely used method of inhibiting stored engines.

The Need for a Reconditioning Process.

Whilst static inhibiting is not fully effective it does at least prevent the more vicious forms of corrosion—if correctly applied with an effective inhibiting fluid. In the aftermath of war many engines found their way into store without proper treatment against corrosion and as a result engine manufacturers are faced with a large number of rusted engines requiring strip and repair.

Napiers have studied these inter-related problems of reconditioning corroded engines at a minimum cost and of ensuring that future inhibiting would prove effective. As a result, a dynamic process has been developed by which corroded engines can be cleansed of residual rust and simultaneously protected against further corrosion during a short " proving run " on fuel and oil supplied from a servicing trolley specially designed for the work.

The Reconditioning Process.

The basis of the reconditioning process is an engine run of about 30 minutes duration, during which a detergent is circulated throughout the interior of the engine. The detergent (Metlgard) removes any rust already formed and simultaneously neutralises the pitted surfaces against further corrosion, the disintegrated rust being expelled through the exhaust with the products of combustion.

Dynamic Inhibiting.

The reconditioning run is followed by an inhibiting run during which an inhibitor fluid is introduced into the fuel supply-line, the fuel being used as a vehicle to carry the inhibitor into the engine. The fuel is used in the combustion process, leaving a film of inhibitor on the internal surfaces of all components in the combustion area and passing down past the pistons effectively to coat the lower cylinder walls. In its passage through the induction system the fuel carries the inhibitor through the carburettor and supercharger, treating bearings and all adjacent surfaces adequately, while at the same time the storage oil in the sump of the engine (containing an inhibiting additive) is circulated round the lubrication system, thus reaching and inhibiting all the components contained in it or served by it.

Results of Dynamic Treatment.

The reconditioning process was developed to deal quickly and economicall y with the workof reconditioning engines already rusted from the various causes previously discussed, while the dynamic inhibiting scheme is primarily aimed, not at supplanting the static method (which is efficient as far as it goes) but at protecting components which *the static method fails t. reach* (such as propeller-bearings, reduction gears, supercharger bearings and drives, lower cylinder walls, etc.). For the protection of the cylinders which are easy of access) direct application by

Fig. 2.—Corrosion of exhaust port in sleeve valves.

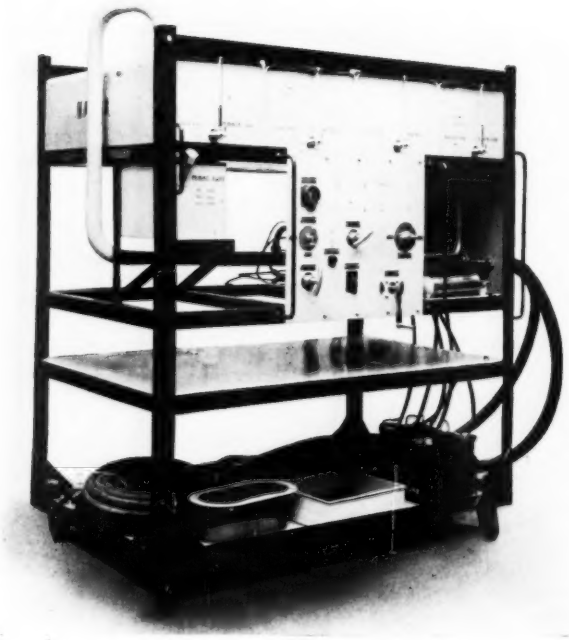


Fig. 3.—"Napier" engine servicing trolley.

spray-gun is still retained. Thus, the anti-corrosion protection afforded by *the two methods in combination* is absolute and complete.

Improvements in any servicing process, however effective, are useless if they cannot be reliably applied by average personnel in a reasonable time. To cater for this, the equipment required for both the reconditioning and dynamic inhibiting process has been combined in a single mobile unit, the Napier Engine Servicing Trolley. This trolley goes far towards putting the whole system of reconditioning and inhibiting aero-engines on a production-line basis. The method employed is both simple and effective ; the engine is run for a short period—without a propeller or substitute flywheel—as and where it stands in its packing case on the floor. This enables the work to be carried out with the minimum amount of dislocation to the engine store or maintenance shop.

THE "NAPIER" ENGINE SERVICING TROLLEY.

The Servicing Trolley, although designed primarily for treating "Sabre" engines, can be readily adapted for use on other types of engines by the provision of suitable couplings. The trolley is assembled on a three-tiered frame of angle-iron with a lifting-eye at the top of each upright and a rubber-tyred castor on each foot. The lifting-eyes enable the trolley to be lifted by crane and swung into position near the engine to be treated, while the castors provide easy manœuvrability for connection of the fluid and electric systems supplying the engine.

The upper tier is devoted to fluid storage tanks that communicate with a grouped union panel on the front of the trolley. Each union is clearly labelled and fitted with a detachable coupling hose equipped with metal tags to indicate the particular service for which each length is designed. In addition, a simple colour identification scheme is employed. When all the tanks are charged the trolley contains 40 gallons of lead-free fuel, 20 gallons of inhibitor mixture, 20 gallons of storage oil and 3 gallons of priming fluid, sufficient for the treatment of about 16 engines. An instrument-panel is mounted below the fluid tanks on the operating side and on it are mounted the fuel and oil priming pumps, the fuel-and-inhibitor changeover cock and an engine starting system, the latter includes a rotary switch by means of which the four magnetos of the engine under treatment can be checked for "rev-drop" during the processing run.

The centre and lower shelves form tool and equipment racks required for stowing the drain trays, hose-lines, coolant-tank, temporary exhausts, engine control levers and other accessories, when the trolley is being moved from site to site. The lower shelf also carries the two 12-volt batteries employed to operate the starting system. An auxiliary instrument panel to record the behaviour of engines under treatment is included among the accessories and is attached to the left-hand induction elbow of the engine. The panel contains an oil pressure gauge, tachometer, and coolant thermometer.

TESTING FOR REJECTS.

Visual assessment of corrosion, either through the sparking plug bores or by removal of cylinder-heads, is unsatisfactory because of the divergence of opinion which inevitably results concerning the amount of corrosion that can be accepted. By the method described below, however, engines are effectively divided into those that can be safely reconditioned and those which require strip and rebuild.

Fifteen minutes after some 15 cc. of "Metlgard" detergent has been sprayed on to each of the cylinder walls and sleeve valves (through the sparking plug bores and valve ports) the engine

is turned over by hand to test the " grip " of the residual corrosion and to circulate the fluid.

If the engine requires great force to turn it after the prescribed period of 15 minutes it must be assumed that the corrosion is serious and the engine must be set aside for strip and overhaul. If, however, the engine can be turned without undue roughness it is capable of dynamic reconditioning and the work can proceed at once.

The Reconditioning Run.

To prepare for the run, a further 10 cc. of " Metlgard " per cylinder is circulated round the cylinders and valves by hand-turning, after which the trolley is brought into position and the various supply lines are connected.

The engine is now ready for the reconditioning run and the sparking plugs are fitted, together with the auxiliary instrument panel, temporary exhausts and coolant system, throttle control extensions and drain trays; after which the engine is primed and started in the usual way. The engine controls are then set to give 2,000 r.p.m. After 15 minutes of running at this speed the engine is shut down and cooled sufficiently for a further injection of " Metlgard " after which it is run for a further 15 minutes as before.

On completion of the second run, the coolant system is flushed and drained with cold water twice and the reconditioning is complete.

The Dynamic Inhibiting Run.

The dynamic inhibiting treatment must be carried out not later than 24 hours after reconditioning to ensure that no condensation attacks the unprotected surfaces. For the inhibiting run the engine is started and stabilised at 1,500 r.p.m., after which it is switched from the ordinary fuel to the inhibited fuel by means of the change-over cock on the trolley-panel. After five minutes of running on the inhibited mixture, the cock is turned off, and the engine allowed to stop from fuel starvation. When cool enough to handle, the valves and cylinders are hand sprayed with inhibitor and the inhibiting process is complete.

Summary and Conclusions.

To the probable question " Is it in order to clean out rust in this way and issue reconditioned engines without inspection ? " there are two answers. First, exhaustive tests confirm that " Metlgard " positively neutralises previously rusted areas against further corrosion ; and secondly, to embrace the possibility of residual rust having damaged the engine, an instrument panel is provided with the trolley to record the behaviour of engines under treatment. The reconditioning run is itself a proof of functioning and if the engine has suffered serious damage while in store, the temperature, pressure, and coolant readings will reveal it during treatment.

In conclusion, as already stated, the practical success of processes such as these, is as much dependent on the man-hours involved as on the merits of the treatment, and engineering history bristles with effective ideas that have had to be abandoned on grounds of man-hour cost. In this connection the Napier Servicing Trolley is the outcome of development aimed at reducing the work of reconditioning corroded aero-engines to the minimum and as is so often the case with

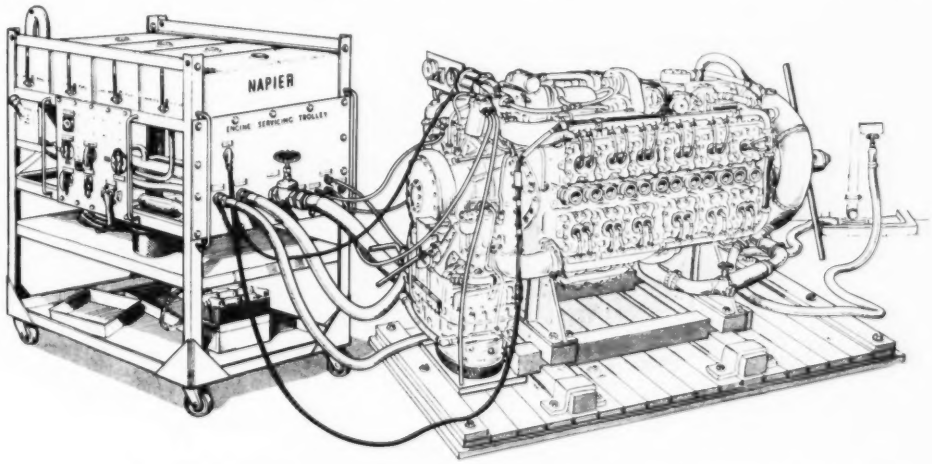


Fig. 4.—NAPIER ENGINE SERVICING TROLLEY connected to a Napier "Sabre" engine for a reconditioning or inhibiting run. The balance characteristics of "Sabre" engines make it possible to run them at up to 2,000 r.p.m. without a propeller or substitute flywheel.

Fig. 5.—Badly corroded reduction-gear balance-arm after long period of storage; typical of parts not reached by protective fluids under static inhibiting.

successful equipment—not only is the objective attained but incidental advantages are achieved as well. The trolley makes the running-up of stored engines so simple and straight forward a task that Storage Units can give all their engines a periodical proving run that automatically re-inhibits them, as a matter of routine.

The most critical time for knowing whether an engine is fully serviceable or not, is when it is withdrawn from store for immediate despatch to an Operational Unit for flying duties. With a Napier Engine Servicing Trolley on hand, it is the work of a few minutes to give the engine a dynamic inhibiting run (or even a reconditioning run as well if necessary) and thus prove serviceability before despatch. In this way the storage unit is assured that all engines received by Operational Units are fit for immediate service.

Development and Testing.

To prove the reliability of the reconditioning and inhibiting treatments described in these notes, extensive tests were made during the development period and it was from observations of these that the final technique was established.

In addition to repeated trials, rusted sleeves were installed in engines and after reconditioning treatment were then subjected to both normal and acid-accelerated corrosion tests. The results were most conclusive in that subsequent corrosion occurred only on areas not previously corroded and subsequently neutralised. The trials showed that dynamic inhibiting gives an adequate deposit of inhibitor on all the internal surfaces of the engine, including the reduction gears, the lower part of the cylinder walls, and the supercharger and induction systems.

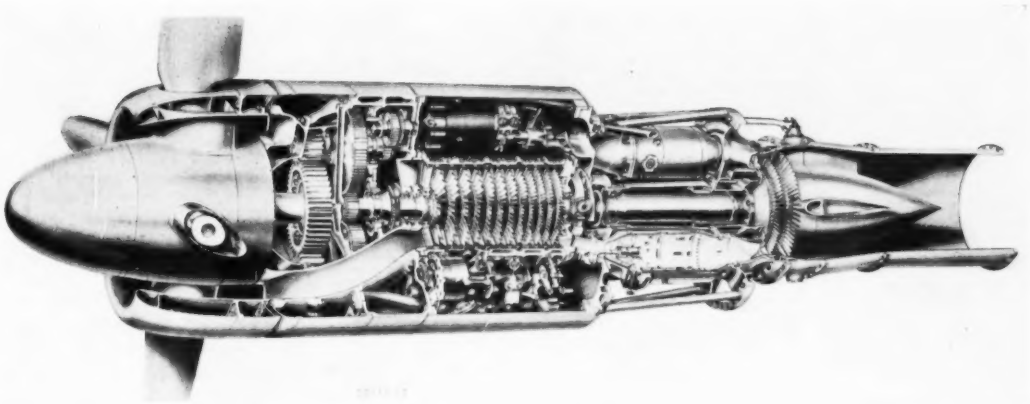
A new "Sabre" engine was subjected to a severe weathering test under extreme conditions of humidity and condensation over a long period in the Napier cold-weather chamber. The temperature was continually varied from −15°C. to average shop temperature in repeated cycles and this treatment produced a continuous deposit of condensation and melting frost on the engine and walls of the weather chamber. The latter was 1 in. deep in water on conclusion of the tests and all the hollows on the outside of the engine were heavily water-logged.

When the engine was stripped examination revealed that the inhibiting treatment had been most satisfactory; inhibitor had penetrated to all the working parts and the film had been maintained throughout. The bores, crankcase, reduction gears, supercharger, induction systems and fuel and oil pumps were entirely free from rust although there were very small traces on some of the sleeves (the static inhibiting of the sleeves was, of course, omitted during this test). The fuel pump was returned to the manufacturers who reported "All components of the pump were found to be well covered with inhibiting oil, i.e., the impeller chamber and blades, relief valve guide and underside of diaphragm, centre pin and underside of seal were all well coated. The rotor chamber was half full of oil and the blades and the centre sleeve were therefore adequately protected. There was no indication of rust or water condensation. This method of inhibiting is therefore satisfactory."

Separate tests were undertaken to confirm that the dynamic cleansing and reconditioning treatments have no deleterious effect on engine starting or running. These established that no gumming or fouling of piston-rings, sparking-plugs, priming jets, injectors or carburettor mechanisms took place.

Further development is in hand to include protection of the coolant system which, though much less critical, is nevertheless subject to corrosion attack. It is felt that this work may bring to light facts interesting enough to warrant another article on this post-war problem of preventing corrosion in stored aero-engines.

The Napier "Naiad" Aero Engine.



Napier "Naiad" Engine.

The Napier "Naiad" is a gas-turbine aero-engine designed to give a total power output of 1,590 e.b.h.p. with a single-rotation, constant-speed, braking propeller and a residual jet.

The majority of the thrust is obtained from the propeller, but it is augmented by an additional thrust of up to 6 per cent. obtained by discharging the exhaust gases from the engine in the form of a jet, the value depending on the flight condition. The propeller is fully feathering, and its braking action is utilised in reducing the landing run.

The designed normal maximum take-off power is 1,500 b.h.p. at the propeller and a jet thrust of 241 lb., while cruising power is 978 b.h.p. and 182 lb. thrust. Under tropical conditions it is estimated that take-off power will be 1,194 b.h.p. and 204 lb. thrust at the jet. These powers are obtained from an engine which has a maximum diameter of only 28 ins., and an overall length of 8 ft. 6 in., lending itself to the compact installation which is so important to the aircraft designer. The weight of the engine is 1,095 lb., giving the very favourable ratio of 1.45 b.h.p. per lb. weight.

The engine is of the axial compressor, straight-through flow type, the annular intake enabling full advantage to be taken of ram effect by passing air directly into the axial compressor. The compressor and turbine are mounted on coupled, co-axial shafts and a spur-type reduction gear transmits the drive to the co-axial propeller shaft. From the compressor the air is delivered to five detachable, parallel-sided combustion chambers into which fuel is sprayed. Approximately 25 per cent. of the air is delivered into the inner chamber where it is burnt with the fuel, while the remainder passes through the outer chamber where it assists cooling. Towards the rear of the inner chamber a series of radial holes permit the burnt gases and relatively cool air to mix, thus giving at the turbine inlet a mass flow of hot gases at the required temperature. The combustion of the mixture is a continuous process and the effusion of the gases provides kinetic energy to operate a turbine which drives the axial compressor and the propeller. After leaving the turbine the gases are discharged to atmosphere by way of the jet pipe.

The various services essential to the engine, such as the fuel pumps, the oil pressure and scavenge pumps and the propeller governor, are all driven off the reduction gears, and a shaft is provided on the engine to drive an ancillary gear-box for the various airframe services.

Provision is made for the use of either an electric starter motor or a turbine-type cartridge starter. Igniter plugs are fitted to two of the combustion chambers for starting purposes and since only

one is necessary, due to incorporation in the design of flame propagation tubes which interconnect all the combustion chambers, the other is available as a reserve.

Control of the engine is effected through a single power lever, which selects the required combination of engine fuel and speed and propeller speed for optimum power output. The fuel control system incorporates a variable-stroke reciprocating fuel pump that automatically regulates the fuel supply in accordance with the requirements of the engine for the particular operating conditions encountered.

Provision is made for mounting the engine from a ring situated at the approximate mid-section of the engine and attached to the compressor casing. The centre support plate to which the ring is bolted also embodies an external fireproof bulkhead which separates the compressor bay from the turbine and combustion chambers bay. In the bottom of the centre support plate is formed a small supplementary oil sump fitted with an individual scavenge pump. This pump returns to the main sump oil from the turbine rotor front bearing and from the gear teeth coupling between the compressor and turbine rotor shafts.

A feature of the engine is that an external oil tank is not required since the reduction gear rear casing, which houses the main oil pumps, is formed internally to provide sufficient oil storage capacity to meet the engine requirements.

Napier "Naiad"-Lincoln.

A Napier "Naiad" Propeller Turbine engine has been installed in the nose of a "Lincoln" Bomber for air tests.

It is usual for the first flight of a new type aero engine to be made in a flying test bed, and this practice makes it possible for engineers to study the many problems which arise during Air Tests of a new type engine, without affecting the performance of the aircraft.

The illustration shows the machine being demonstrated at The Society of British Aircraft Constructors' Display, held at Farnborough, in September last, and was the first occasion that the "Naiad" engine had been seen in the air. This was achieved by some excellent team work, by the Works in building and testing the engine in record time when it had been decided to fly this machine in the Display, and by the Installation Section who received the engine on September 3rd and installed and air tested it and delivered the machine to Farnborough on September 6th.

Lincoln Bomber in flight, with Napier "Naiad" engine installed in nose of machine for air tests.